

Undernourishment and economic growth

The efficiency cost of hunger

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DEVELOPMENT
PAPER

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RÉSUMÉS EN FRANÇAIS
RESÚMENES EN ESPAÑOL

Food
and
Agriculture
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of
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United
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FOREWORD

The positive effects of increases in per caput GDP on average nutrition at country level have been amply demonstrated in both the theoretical and empirical literature. Is there a reverse linkage, i.e. does better nutrition of the population facilitate economic growth? This paper examines the issue cast in terms of one central dimension of nutrition: food energy intakes.

It is accepted that under-nutrition constrains the productivity and hence earning capacity of individuals in a society in a number of direct and indirect ways. Under-nourished adults can carry out a reduced work-load and are more susceptible to illness, while under-nourishment reduces the ability of children to learn, by reducing school attendance and absorption capacity. In extreme cases, under-nourishment in children causes mental retardation and other handicaps which are eventually translated into reduced productivity in later life. Thus, persistent or episodic under-nourishment may have long-term as well as immediate effects on productivity and working capacity.

Indeed, the empirical literature at the microeconomic level (individuals and households) has provided evidence linking better nutrition to higher levels of productivity. Thus, in societies with a large number of undernourished, overall labour productivity, and consequently, returns to investments in the productive capacity of aggregate labour input will be lower. In such societies, overall growth will be compromised. Plausible as such a result may seem, evidence in supporting it using recent advances in data availability and improvements in econometric technique was lacking.

It is precisely this void in empirical evidence linking under-nutrition and economic growth at the aggregate level that the present paper addresses. Namely, the paper investigates the magnitude of the effect of under-nourishment on economic growth and attempts to identify the channels of transmission (direct effects on productivity and via impacts on health). In addition to this basic relationship, a number of other important relationships are investigated in the paper: (a) regional differences regarding the impact of under-nourishment on growth; (b) the impact that possible errors in measuring nutritional variables may have on the robustness of the estimated nutrition-growth relationship; and (c) the existence of "nutritional traps", i.e. the vicious circle of low nourishment, low economic growth, low nourishment. Thus the paper makes a significant contribution to the literature on the factors that account for the differences in growth performance across countries and regions.

The benchmark result of the study indicates that increasing the average daily energy supply (DES) to 2 770 kcal per person per day in a sample of countries that were below that level, could have increased the average annual GDP growth rate by 0.8 percentage points during the period 1960-1990 covered by the study. If only the countries with DES levels below 2 770 calories/caput/day are considered, then raising the average caloric intake to that level would add 1.13 percentage points to their annual growth rate. Although the results should be looked at from a "ceteris-paribus" perspective (i.e. as marginal changes all other things being equal), this basic result provides an idea on the magnitude of cumulative growth losses in countries suffering from under-nourishment, especially if one considers that the average annual growth rate in those countries for the period under consideration was around two percent.

This One



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The paper also suggests the existence of nutritional growth traps. The mean growth rate of countries having low levels of food inadequacy is about three times as high as the mean growth rates in countries with high levels of food inadequacy.

A very important implication of the study, for developing country governments and donors alike, is that policies (including development aid) which reduce or eliminate under-nourishment in developing countries should not be viewed only in terms of their welfare and humanitarian benefits, but also in terms of their growth-promoting dimensions. It is also hoped that by publishing the present paper, FAO opens an important debate on the short- and long-term implications of poverty and hunger for the overall development effort.



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CONTENTS

	page
ABSTRACT	1
RÉSUMÉ	2
RESUMEN	3
ABSTRACT (ARABIC)	4
1. BASIC EMPIRICAL REGULARITIES	5
1.1 Introduction	5
1.2 Stylized facts	9
1.3 Malnutrition and endogenous growth	11
1.4 Malnutrition within a neo-classical framework	12
1.5 Non-linearities and threshold effects	13
2. ROBUSTNESS	19
2.1 The Svedberg critique, unobserved, country-specific heterogeneity, and random measurement error	19
2.2 Sensitivity to data structure	22
3. TRANSMISSION MECHANISMS	27
3.1 Direct versus indirect transmission mechanisms	27
3.2 Life expectancy	28
3.3 Schooling	30
4. CONDITIONAL RESPONSE	33
4.1 Nutritional growth traps ?	33
4.2 Empirical specification	35
4.3 Escaping the malnutrition trap: some tentative findings	39
5. ENDOGENEITY AND STRUCTURAL ESTIMATION	41
5.1 Life expectancy	41
5.2 Schooling	47
6. THE EFFICIENCY COST OF HUNGER: A QUANTITATIVE ASSESSMENT	51
7. CONCLUDING REMARKS	55
REFERENCES	57

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ABSTRACT

This paper considers the impact of two measures of nutritional status on the growth rate of GDP per caput: the prevalence of food inadequacy (PFI), and the dietary energy supply (DES) per caput, as reported by the FAO in the *Sixth World Food Survey*. A surprisingly strong relationship appears to link economic growth to nutritional factors, and is robust to econometric procedures that correct for unobserved, country-specific heterogeneity, as well as measurement error or endogeneity concerns raised by the recent critique of FAO data by Svedberg (1999). The impact of nutrition on economic growth would appear to operate directly, through nutrition's effect on labour productivity, as well as indirectly, through improvements in life expectancy. Depending upon the empirical specification that is chosen, the point estimates imply that inadequate nutrition is responsible for a shortfall of between 0.23 and 4.7 percentage points in the annual growth rate of GDP per caput worldwide, with the higher figure, ironically, corresponding to estimation techniques that correct for the data problems identified by Svedberg. Aside from its effect on human welfare, the *efficiency* cost of hunger would therefore appear to be extremely important. Even when allowing for substantial overestimation of the PFI or underestimation of the DES per caput for sub-Saharan Africa, the results provide a compelling explanation for the growth shortfall suffered by the African continent, with estimates ranging from 0.16 percentage points to 4.0 percentage points of lost growth. Seen from another angle, countries with above-median PFI would have seen their annual growth rate of GDP per caput increase by 1.6 percentage points if they had raised their DES per caput to 2,770 kcal / day. However one looks at the problem, achieving the goal of reducing the prevalence of food inadequacy by half by 2015, as enunciated at the World Food Summit of 1996, would therefore not only improve human welfare considerably, but also substantially increase the rate of economic growth.

Résumé

Dans ce document, on examine le rapport entre le taux de croissance du PIB par habitant et deux mesures de l'état nutritionnel: la prévalence de l'insuffisance alimentaire et la disponibilité énergétique alimentaire par habitant, tels qu'établies par la FAO dans la *Sixième enquête mondiale sur l'alimentation*. Il semble qu'il existe un lien extrêmement étroit entre la croissance économique et les facteurs nutritionnels, quelles que soient les procédures économétriques destinées à apporter des corrections en cas d'hétérogénéité spécifique nationale non observée, ainsi qu'aux préoccupations concernant des erreurs de mesure ou des cas possibles d'endogénéité soulevées par les critiques récentes des données FAO par Svedberg (1999). Les effets de la nutrition sur la croissance économique se font directement sentir au niveau de la productivité du travail, et indirectement, grâce aux progrès de l'espérance de vie. Selon la spécification empirique retenue, les estimations ponctuelles font apparaître qu'une nutrition inadéquate est responsable d'un déficit compris entre 0,23 et 4,7 points de pourcentage du taux de croissance annuel du PIB par habitant dans le monde, le chiffre le plus élevé résultant, il convient de le relever, de techniques d'estimation conçues pour corriger les problèmes de données relevés par Svedberg. Mis à part les effets sur les conditions de vie, le coût de la faim du point de vue de l'efficacité semblerait donc extrêmement important. Même si l'on tient compte d'une éventuelle surestimation importante de la prévalence de l'insuffisance alimentaire ou d'une sous-estimation de la disponibilité énergétique alimentaire par habitant en Afrique subsaharienne, les calculs expliquent de manière convaincante le déficit de croissance que connaît le continent africain, les estimations allant de 0,16 point de pourcentage à 4,0 points de pourcentage de croissance perdue. Sous un autre angle, les pays dont la prévalence de l'insuffisance alimentaire est supérieure à la médiane auraient enregistré une augmentation du taux de croissance annuel de leur PIB par habitant de 1,6 point de pourcentage s'ils avaient porté les disponibilités énergétiques alimentaires par habitant à 2 770 kcal/jour. Quelle que soit la façon dont on examine le problème, la réduction de moitié de la prévalence de l'insuffisance alimentaire pour 2015 au plus tard, objectif déclaré du Sommet mondial de l'alimentation en 1996, permettrait non seulement de beaucoup améliorer les conditions de vie, mais aussi d'augmenter considérablement le taux de croissance économique.

Resumen

En el presente documento se examinan los efectos sobre la tasa de crecimiento del PIB per cápita que tienen dos mediciones del estado nutricional, a saber la prevalencia de la insuficiencia de alimentos (PIA) y el suministro de energía alimentaria (SEA), según informa la FAO en la *Sexta Encuesta Alimentaria Mundial*. Parece haber una relación asombrosamente estrecha entre el crecimiento económico y los factores nutricionales, relación que es resistente a los procedimientos econométricos orientados a corregir la heterogeneidad no observada específica de los países, así como errores de medición o las preocupaciones con respecto a la endogeneidad que se plantean en la crítica de los datos de la FAO realizada recientemente por Svedberg (1999). Al parecer, las consecuencias de la nutrición para el crecimiento económico son tanto directas, mediante los efectos de la nutrición sobre la productividad de la mano de obra, como indirectas, mediante las mejoras en la esperanza de vida. Según la especificación empírica que se elija, las estimaciones puntuales implican que una nutrición insuficiente es la causa de una reducción de la tasa anual de crecimiento del PIB per cápita en todo el mundo comprendida entre el 0,23 y el 4,7 por ciento, correspondiendo irónicamente la cifra más alta a las técnicas de estimación que corrigen los problemas de datos indicados por Svedberg. Además de sus efectos sobre el bienestar humano, el costo de *eficiencia* del hambre parece ser sumamente importante. Aun teniendo en cuenta la posibilidad de una estimación muy excesiva de la PIA o una estimación insuficiente del SEA per cápita para el África subsahariana, los resultados ofrecen una explicación convincente del déficit de desarrollo sufrido por el continente africano, variando las estimaciones del crecimiento no registrado entre el 0,16 y el 4,0 por ciento. Examinando la cuestión desde otro punto de vista, si los países con una PIA superior a la mediana hubieran aumentado su SEA per cápita hasta 2 770 kcal/día, se habría observado un aumento del 1,6 por ciento de su tasa anual de crecimiento del PIB per cápita. Por consiguiente, comoquiera que se considere el problema, el logro del objetivo de reducir a la mitad la prevalencia de la insuficiencia de alimentos para el año 2015, enunciado en la Cumbre Mundial sobre la Alimentación de 1996, no sólo mejoraría notablemente el bienestar humano, si no que además aumentaría considerablemente la tasa de crecimiento económico.

ملخص

أتناول في هذه الورقة تأثيرات مقياسين لحالة التغذية على معدل النمو في نصيب الفرد من الناتج المحلي الإجمالي وهما انتشار عدم كفاية الأغذية ونصيب الفرد من إمدادات الطاقة الغذائية على النحو الذي أشارت إليه منظمة الأغذية والزراعة في نشرة "المسح الغذائي العالمي السادس". ويبدو أن هناك علاقة قوية بصورة مثيرة للدهشة تربط بين النمو الاقتصادي والعوامل التغذوية، وترتبط بعمليات الاقتصاد الرياضي التي تصحح التباينات القطرية غير الملحوظة فضلا عن أخطاء القياس أو الاهتمامات الداخلية التي أثارها الانتقادات الأخيرة التي وجهت لبيانات المنظمة من قبل سفيدبيرج (١٩٩٩). ويبدو أن تأثيرات التغذية على النمو الاقتصادي تمارس بصورة مباشرة من خلال تأثيرات التغذية على إنتاجية العمل، وبصورة غير مباشرة من خلال التحسينات في العمر المرتقب عند الميلاد. واعتمادا على الموصفات العملية المختارة، تعني التقديرات التي وضعتها للنقاط أن عدم كفاية الأغذية مسؤول عن نقص ما بين ٠,٢٣ و ٤,٧ نقطة في المائة في معدل نمو نصيب الفرد من الناتج المحلي الإجمالي في مختلف أنحاء العالم. ومن المفارقات أن الرقم الأعلى يتوافق مع تقنيات التقدير التي تصحح الوضع الناجم عن مشكلات البيانات التي حددها سفيدبيرج. فبالإضافة إلى تأثيرات الجوع على مستوى معيشة البشر، فإن تكلفة المحافظة على "الكفاية" لدى الفقراء ستبدو، لذلك، شديدة الأهمية. فحتى بعد مراعاة المبالغيات الكبيرة في تقدير انتشار عدم كفاية الأغذية أو التقليل من قيمة نصيب الفرد من إمدادات الطاقة الغذائية في أفريقيا جنوب الصحراء الكبرى، فإن النتائج التي توصلت إليها توفر تفسيراً قاطعاً للنقص في النمو الذي تعاني منه القارة الأفريقية حيث تتراوح التقديرات بين ٠,١٦ نقطة في المائة و ٤,٠٠ نقاط في المائة من نقص النمو. وإذا نظر إلى الأمر من زاوية أخرى، فإن البلدان التي يزيد فيها معدل عدم كفاية الأغذية عن المتوسط ستزيد معدل النمو السنوي في نصيب الفرد من الناتج المحلي الإجمالي بنسبة ١,٦ نقطة في المائة إذا زادت من نصيب الفرد من إمدادات الطاقة الغذائية إلى ٢٧٧٠ سعرا حراريا يوميا. غير أنه عندما ينظر المرء إلى المشكلة المتعلقة بتحقيق هدف خفض انتشار عدم كفاية الأغذية بمقدار النصف قبل عام ٢٠١٥، على النحو الذي تقرر في مؤتمر القمة العالمي لعام ١٩٩٦، فإنه لا يسعى إلى تحسين مستوى معيشة البشر بدرجة كبيرة فحسب بل وزيادة معدل النمو الاقتصادي زيادة كبيرة.

1. BASIC EMPIRICAL REGULARITIES

1.1 Introduction

Despite the substantial progress that has been made in recent years in explaining cross-sectional differences in growth performance, as well as the plethora of variables that are advanced by different authors as providing a piece of the explanation, remarkably little has been done lately in terms of aggregate cross-sectional econometrics in order to evaluate the impact of nutritional concerns on economic growth.

The converse, of course, is not true. In a recent paper, one of the most prominent authors associated with the new empirical growth literature, William Easterly, finds, among a multitude of other indicators of the quality of life, that daily calorie intake increases with per caput GDP, the coefficient associated with the latter, when estimating in first-differences (in order to control for unobserved, time invariant, country-specific effects) and instrumenting using GDP per caput lagged two periods (in order to control for random measurement error or potential endogeneity) is equal to 538 with a corresponding t-statistic of 3.22. This implies that an increase in GDP per caput of 1 percent is associated with an increase in daily calorie intake of 538 kcal / day. The purpose of the present paper is essentially to reverse the causality in a regression such as Easterly's in order to assess the contribution of nutritional concerns to the growth rate of GDP per caput. As such, the prevalence of hunger is not only an indicator of what Amartya Sen would refer to as "deprivation" —which is, of course, an extremely important cost in and of itself— but also potentially a fetter that moves one away from the efficient frontier.

One of the main findings of this paper is that there is a statistically significant, and quantitatively important impact of nutrition on growth, and that this result is robust to the use of three different datasets and to the application of a multitude of different econometric procedures, ranging from simple pooled time-series cross-section regressions estimated using ordinary least squares (OLS), the inclusion of country-specific fixed effects, a switching regression specification with unknown sample separation estimated by Maximum Likelihood, Generalized Method of Moments (GMM) estimation preceded by first-differencing, and GMM estimation in which a growth regression is paired with a life expectancy equation. Interestingly, it would appear that the effect of nutrition on growth operates in part directly, probably through its impact on labour productivity, as well as indirectly, through improvements in life expectancy which, in turn, spur faster growth.

In theoretical terms, these econometric results concerning the *direct* effect of nutrition on growth are easy to justify on the basis of the substantial literature that goes back to Leibenstein (1957), Mazumdar (1959), Mirlees (1975), Stiglitz (1976), Bliss and Stern (1978), or Dasgupta and Ray (1984), linking better nutrition to higher labour productivity. In terms of the ample, though sometimes controversial, micro-econometric evidence regarding the impact of nutrition on labour productivity, our results should also come as no surprise. A number of papers from the 1980s all find substantial effects of nutrition on labour productivity (for the standard surveys, see Barlow, 1979, Martorell and Arrayave, 1984, Strauss, 1985, Srinivasan, 1992, Behrman and Deolalikar, 1988), although these results would appear to be extremely sensitive to specification and, in particular, to controlling for household-specific fixed effects.¹ The results

¹ The comparison between the papers of Strauss (1986) and Deolalikar (1988), which use the same dataset, but where Deolalikar uses fixed effects and instrumental variables, is striking in this respect. Strauss finds effective family labour input to be increasing in daily calorie availability while Deolalikar finds that output is not affected by daily calorie intake. Mark Rosenzweig (1988), in his survey of labour markets in low-income countries in the *Handbook of Development Economics*, is less convinced of the impact of daily calorie availability on labour productivity, stating that both of these studies "do not find much, if any, rigorous supporting evidence." (p. 727) For a more recent effort in this direction, see Haddad and Bouis (1991).

presented in what follows would appear to indicate that many of the findings reported at the microeconomic level translate into statistically discernible effects at the aggregate level.

The paper which is perhaps the closest in spirit to what follows is Wheeler (1980) (see Gwatkin, 1983, for a survey of the cross-country work that was done in the late seventies and early eighties), who estimated, using the relatively scarce data available twenty years ago, a system of four equations using three-stage least squares (3SLS).² His system comprised an output equation, a nutrition equation, a health equation, and an education equation, with the three latter variables all appearing in the production function as determinants of "effective labour". All equations were specified in terms of growth rates. Wheeler found an elasticity of output with respect to daily calorie availability of 2.652, which was significant at the usual levels of confidence (standard error of 0.391). While his results are easy to criticize today given the advances in data availability and in econometric technique, they do indicate that a statistically significant impact of nutrition on growth had been identified twenty years ago.

The results should also come as no surprise in light of recent work undertaken by the Development Research Group of the World Bank: McCarthy, Wolf and Yu (2000) find, for a substantial number of countries in sub-Saharan Africa, that the presence of malaria reduces the annual growth rate of GDP per caput by 0.25 percentage points. Thus, a disease that has an important direct effect on human welfare also entails important efficiency losses. The results presented in the present paper suggest that the costs associated with hunger, in terms of lost growth, are probably significantly greater than those associated with malaria.

The structure of the paper is as follows. In the remainder of part 1, the stylized facts concerning the relationship linking the growth rate of GDP per caput to two measures of nutritional status are established, namely (i) the prevalence of food inadequacy (PFI) and (ii) the dietary energy supply (DES) per caput, as reported in the *Sixth World Food Survey* of the FAO. A pooled time-series cross-section dataset is used in which each observation corresponds to a country-decade as well as with the standard long-run dataset, covering a thirty-year time span, first analysed by Levine and Renelt (1992). A theoretical interpretation of the results is provided in the context of an extremely simple endogenous growth model of the "AK" variety, and in a neo-classical model in the tradition of Solow. The potential existence of (i) non-linearities in the relationship and (ii) threshold effects of the impact of the DES per caput on growth which depend upon the initial level of GDP per caput are established.

Part 2 considers the robustness of the preliminary results presented in part 1. Loosely speaking, the basic empirical results are subjected to a battery of statistical procedures with the aim of destroying them. In particular, the criticisms of FAO data recently formulated by Svedberg (1999) are taken into account, and the basic specification is estimated using a first-differencing procedure followed by Generalized Method of Moments (GMM) estimation which corrects, simultaneously, for the problems of country-specific and random measurement errors raised by Svedberg. The result is that the statistically significant impact of the DES per caput and the PFI on the growth rate of per caput GDP is not only robust to this procedure but also increases in quantitative terms. The initial results are re-estimated using country-specific fixed effects, using the between estimator, and using an alternative dataset due to Sachs and Warner (1997a, 1997b). As with the GMM-first-differencing procedure, the basic result of a statistically significant impact of the DES per caput and the PFI on the growth rate remains.

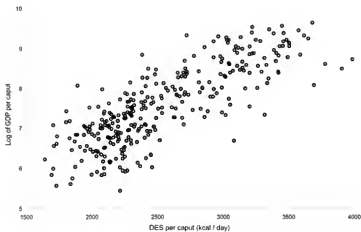
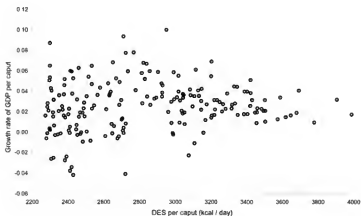
² Fogel (1989) also considers the impact of nutrition, from an historical perspective, although the focus is more on the reverse causality.

Part 3 begins investigating those *indirect* transmission mechanisms by which nutritional status might affect the growth rate of GDP per caput, in contrast to the *direct* effect that operates through the productivity of the labour force. Two potential indirect transmission mechanisms based on human capital arguments are considered: schooling and life expectancy. Including measures of both of these variables in the basic specification, regardless of the estimation procedure that is chosen, yields roughly the same, statistically significant, coefficient on the nutritional variables. The conclusion is that, while an indirect effect of nutrition on growth operating through the impact of the human capital variables cannot be excluded, the direct effect (operating through labour productivity) is an important transmission mechanism in and of itself. Disentangling the relative contributions of the indirect versus the direct effects is dealt with in part 5.

Part 4 is motivated by the threshold effect and non-linearities uncovered in the analysis of the preliminary results. Therefore, it examines the possibility of the existence of nutritionally-generated "growth traps", in the sense that a country whose population is inadequately fed may be unable to emerge from a low level equilibrium onto a balanced growth path. A simple endogenous growth model is thus formulated that can, potentially, generate such nutritional growth traps. This theoretical model is then parameterized, using a switching regression specification with unknown sample separation, in which countries are divided into a high PFI and a low PFI regime, the distinguishing feature of the former being that convergence effects are absent and that the impact of the DES per caput is present, the distinguishing feature of the latter being that convergence effects are present and nutritional effects are absent. This model is estimated by Maximum Likelihood, and shows that a shortfall of two percentage points in the annual growth rate of GDP per caput can be accounted for by a country belonging to the high PFI regime. The issue of how countries are classified into the two regimes by the switching regression procedure is addressed. Perhaps the most interesting finding is that a group of five Near East and North Africa countries (Algeria, Morocco, Tunisia, Syria and Egypt) managed to emerge from the high PFI regime into the low PFI regime during the 1970s.

Part 5 returns to the issue of identifying the relative magnitudes of the direct effect of nutrition on growth *versus* its indirect effect mediated by human capital variables. To that effect, the section begins with the estimation, by GMM, of a system of two equations in which a growth regression is paired with a life expectancy equation. The DES per caput enters the growth regression directly, but also impacts growth indirectly through its effect on life expectancy, which itself is included in the growth equation and is assumed to be endogenous. It is found that a more complex specification in which a three-equation system is considered in which the additional regression is given by a schooling equation is statistically fragile. Therefore, settle on a two-equation system comprising a growth equation and a life expectancy equation is chosen, but where schooling appears in the growth equation and is assumed to be endogenous (the hypothesis that schooling is exogenous is strongly rejected by a test of this overidentifying restriction). This specification allows me to empirically separate the direct from the indirect impact of the DES per caput on growth. In quantitative terms: an increase of the DES per caput to 2770 kcal/day in those countries where it is below that level would increase the annual growth rate of GDP per caput by 0.53 percentage points directly and by 0.70 percentage points indirectly, yielding a total increase in the annual growth rate of 1.23 percentage points.

Part 6 provides a quantitative assessment of the impact on the annual growth rate of GDP per caput of eliminating food inadequacy or increasing the DES per caput to 2770 kcal/day, based on 8 different estimation procedures for the case of the PFI and 17 different estimation procedures for the case of the DES per caput. For sub-Saharan Africa, the estimated shortfall in the annual growth rate of GDP per caput caused by inadequate nutrition ranges from 0.64 percent to 4.04 percent, even when one assumes that the PFI is overestimated or the DES per

FIGURE 1**Log of GDP per caput as a function of the DES per caput (kcal/day)****FIGURE 2****Growth rate of GDP per caput as a function of the DES per caput**

caput is underestimated by 20 percent. Ironically, the higher figure corresponds to the estimation procedure (GMM with first-differencing) that directly addresses the concerns regarding the data that were raised by Svedberg (1999). These figures imply, over a 30 year period, that the mean GDP per caput of sub-Saharan African nations would have been between 200 and 2 500 dollars higher had food inadequacy been eliminated. The sample is then divided into countries with above-median and below-median PFI. Using the simple pooling results that are probably the least controversial in terms of the existing growth literature, it is found that the gap in the mean GDP per caput between these two groups of countries would have been narrowed from \$US 5 000 to \$US 3 250 in 1990 had the DES per caput been raised to 2 770 kcal / day in the above-median PFI countries. Part 7 concludes, and offers some thoughts regarding the implications concerning poverty that can be drawn from my results.

1.2 Stylized facts

As illustrated by Figure 1, which plots the logarithm of per caput GDP against the dietary energy supply (henceforth, DES) per caput in kcal/day, the correlation between income and nutrition is a well-established empirical regularity (see, for example, the paper by Easterly alluded to above). Each observation in Figure 1 corresponds to a country-decade. While the link between income and nutrition is clear even in a one dimensional plot, this cannot be said of the relationship linking the DES per caput to the growth rate of per caput GDP, as illustrated in Figure 2.

Nevertheless, moving to elementary regression analysis suggests that a link does indeed exist. Indeed, if one regresses the growth rate of GDP per caput on two decade dummies, two continent dummies and 100 *minus* the prevalence of food inadequacy (henceforth, PFI), the coefficient associated with the PFI is positive and significantly different from zero at the usual levels of confidence.³ The estimated relationship is given in column (3) of Table 1. In column (6) of the same table, a similar relationship is considered, where the proportion of the PFI is replaced by the DES per caput. Again, the coefficient associated with the nutritional variable is statistically significant at the usual levels of confidence.⁴

It is, of course, possible to argue that the observed correlation between the growth rate of per caput GDP and the nutritional variables is merely a statistical artefact that stems from the exclusion, in the two regressions, of GDP per caput. That is, it may be that the nutritional variables, given their high level of correlation with GDP per caput, are simply picking up the latter's impact on growth. Columns (4) and (7) of Table 1 show that this is *not* the case. When one includes the initial level of GDP per caput in both specifications, the coefficient associated with the nutritional variables remains statistically significant and of the same order of magnitude. These preliminary results suggest that nutritional concerns have an impact on economic growth, and that this effect does not stem from omitted variables bias. Indeed, the coefficients associated

³ The chosen continent dummies (sub-Saharan Africa and Latin America) are included so as to make the results directly comparable to much of the work undertaken by the Development Research Group of the World Bank.

⁴ It has correctly been pointed out by Ali Gürkan that statistical inference in growth regressions can be rendered dubious because of the potential heteroskedasticity induced by the very calculation of growth rates of GDP per caput. All pooling regression results reported in this paper were therefore run while correcting for this specific form of heteroskedasticity. Results do not differ in any significant manner from those obtained using a White correction, and the latter are therefore presented in order to render the findings more readily comparable with the existing literature.

TABLE 1

Prevalence of food inadequacy (PFI), dietary energy supply (DES) per caput, and economic growth

Benchmark results and non-linearities in the relationship

Method of estimation : OLS (t-statistics below coefficients)

Dependent variable : growth rate of per caput GDP (decade average)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Nutritional variable	none		PFI			DES per caput		
Intercept	0.018	0.006	-0.060	-0.056	-2.755	-0.012	0.003	-0.120
	8.124	0.804	-2.776	-2.468	-2.232	-1.463	0.242	-4.033
1960s dummy	0.021	0.022	0.022	0.020	0.019	0.023	0.022	0.021
	8.001	8.141	8.188	7.437	8.969	8.432	8.147	7.667
1970s dummy	0.019	0.019	0.019	0.018	0.017	0.020	0.019	0.018
	6.234	6.407	6.038	5.868	5.769	6.396	6.297	6.033
Africa dummy	-0.022	-0.020	-0.014	-0.016	-0.011	-0.014	-0.016	-0.015
	-7.586	-5.039	-3.653	-3.726	-2.478	-4.075	-4.190	-4.316
Latin America dummy	-0.019	-0.019	-0.016	-0.017	-0.010	-0.014	-0.013	-0.015
	-6.635	-6.329	-5.568	-5.814	-3.195	-4.546	-4.068	-4.893
Log of initial GDP (by decade)		0.001		-0.003	-0.008		-0.003	-0.004
		0.733		-1.594	-3.395		-1.392	-1.589
Estimated annual rate of convergence (λ)	-1.16E-04		2.82E-04			3.24E-04		
	-0.725		1.488			1.334		
Nutritional variables								
100 - PFI (%)			0.001	0.001	0.104			
			3.659	4.113	2.336			
(100 - PFI (%)) ²			-0.0013					
			-2.428					
(100 - PFI (%)) ³			5.23E-06					
			2.539					
DES per caput (kcal/day)						9.59E-06	1.38E-05	1.11E-04
						3.957	3.432	5.201
DES per caput, squared						-1.81E-08		
						-4.725		
Mean of dependent variable	0.020	0.020	0.020	0.020	0.020	0.019	0.019	0.019
Adjusted R ²	0.293	0.294	0.322	0.326	0.350	0.306	0.309	0.340
F test (zero slopes), p-value	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
σ	0.022	0.022	0.021	0.021	0.021	0.021	0.021	0.021
Number of observations	330	328	322	320	320	316	314	314

Note: each observation corresponds to a country-decade; standard errors are White heteroskedasticity-consistent; threshold value of DES per caput in quadratic specification (column (6)) : 3066 kcal/day. Data source: Growth rate of GDP per caput : World Bank National Accounts; initial GDP per caput: Summers and Heston (1991); DES per caput and PFI : The Sixth World Food Survey (Rome: FAO, 1996).

with log GDP per caput are negative, though statistically insignificant at the usual levels of confidence. This corresponds to the well-known absence of unconditional convergence : when additional explanatory variables, such as measures of human capital (health or schooling) are included in the regression, as shall be seen below, the conditional convergence effects are, as expected, negative and statistically significant.

It is worth putting these initial results in perspective from the quantitative standpoint : an increase of one standard deviation (508 kcal/day) from the mean DES per caput in the sample

(2535 kcal/day) increases the annual growth rate of GDP per caput by 0.7%: over the medium to long term, it is safe to say that this is a substantial effect, the mean annual growth rate of GDP per caput in the sample being 2.0%. Similarly, a decrease of one standard deviation in the PFI (7.05) would also increase the annual growth rate of GDP per caput by 0.7%. Eliminating food inadequacy entirely would raise the growth rate of per caput GDP by 0.64% (the mean value of food inadequacy being of 6 percent in the full sample). These numbers would of course be even larger if one confined one's attention to those countries where the PFI is particularly large. Note finally that the dummy variable indicating that an observation corresponds to a sub-Saharan African (henceforth, SSA) country is negative and highly significant at the usual levels of confidence. This corresponds to the well-known puzzle of the lower rate of economic growth of SSA which is usually robust to the inclusion of additional explanatory variables (see, e.g. Easterly and Levine, 1997, although Sachs and Warner, 1997b, claim to have solved the puzzle). As will be shown below, in contrast to the usual findings of the literature, that the Africa dummy will become insignificant once health indicators and nutritional variables are both included in the specification. It would therefore seem that African specificity in terms of health and nutrition lie behind the puzzle of the low growth rate of SSA.

1.3 Malnutrition and endogenous growth

The most obvious manner of formalizing the preceding empirical results is within the context of the simplest endogenous growth model of the "AK" variety in the tradition of Rebelo (1991).

Let the effective labour input $\tilde{L}_t$ be given by:

$$(1) \quad \tilde{L}_t = (1-m)^\gamma L_t$$

where L_t is the labour force, m is the PFI and γ is a parameter; $(1-m)^\gamma$ therefore represents the productivity of labour. For the time being, m will be treated as an exogenous parameter with respect to the dynamics of the model. Let K_t represent the stock of physical capital. As is usual in endogenous growth models, the labour force is normalized to one ($L_t = 1$) and zero population growth is assumed.⁵ Assuming an additively separable intertemporal utility function with preferences that satisfy constant relative risk-aversion (CRRA) and exponential discounting (at rate ρ), the representative consumer's optimization problem is given by:

$$(2) \quad \max_{\{c_t, K_t\}} \int_0^{\infty} \frac{c_t^{1-\sigma}}{1-\sigma} e^{-\rho t} dt \quad \text{s.t.}$$

$$(3) \quad Y_t = A(1-m)^\gamma K_t$$

$$(4) \quad \dot{K}_t = A(1-m)^\gamma K_t - c_t$$

where the first constraint represents the AK production technology with constant returns to physical capital (Y_t is simply aggregate output and A represents total factor productivity) and the second constraint gives us the law of motion of the stock of physical capital.⁶ The corresponding Hamiltonian is given by:

⁵ This is to avoid the counterintuitive result, that obtains in most endogenous growth models, in which the steady-state growth rate of GDP per caput would be an increasing function of the growth rate of the population; indeed, the steady-state growth rate of GDP per caput would be an increasing function of the labour force itself in most endogenous growth models.

⁶ The usual notation is used whereby a "dot" above a variable indicates its derivative with respect to time; that is $\dot{K}_t = dK_t / dt$.

$$(5) \quad \frac{\dot{c}_t}{1-\sigma} e^{-\rho t} + \mu_t \left(A(1-m)^{\gamma} K_t - c_t \right),$$

where μ_t is the costate variable. By an elementary application of Pontryagin's Maximum Principle and the usual manipulations, the steady state growth rate of consumption, the capital stock, and the growth rate are obtained as:

$$(6) \quad \frac{\dot{c}_t}{c_t} = \sigma^{-1} \left(A(1-m)^{\gamma} - \rho \right)$$

The steady-state growth rate of per caput GDP will thus be a decreasing function of the PFL, as we found empirically in columns (3) and (4) of Table 1. If $1-m$ is replaced by the DES per caput, a similar model corresponding to the results presented in columns (6) and (7) of Table 1 is obtained. One manner of interpreting the preceding formalization (and, for that matter, the neo-classical model that follows below) is in terms of the nutritional efficiency wage model, first suggested by Harvey Leibenstein (1957). As noted by Bliss and Stern (1981), nutritional levels are sufficiently low in many LDCs for workers' productivity to be significantly increased by an increase in food consumption.

1.4 Malnutrition within a neo-classical framework

An alternative formalization of the empirical regularities uncovered in our initial empirical analysis is provided by a simple neo-classical growth model in the tradition of Solow. Assuming a constant returns to scale Cobb-Douglas production technology with aggregate capital and effective labour as inputs, one obtains, using the same parameterization of the effective labour input as above (see equation (1)):

$$(7) \quad Y_t = AK_t^{\alpha} \left[(1-m)^{\gamma} L_t \right]^{1-\alpha}$$

where $\alpha \in (0,1)$ is a parameter. Assuming neo-classical saving behaviour ($\dot{K}_t = sY_t$), where s denotes the investment rate, one obtains the usual equation for the rate of growth of the capital stock, per caput:

$$(8) \quad \frac{\dot{k}_t}{k_t} = sAk_t^{\alpha-1} (1-m)^{\gamma(1-\alpha)} - n$$

where $k_t = K_t / L_t$ denotes capital per caput and

n denotes the (constant) growth rate of the population ($n = \dot{L}_t / L_t$).

In steady-state ($\dot{k}_t = 0$), the level of the capital stock per caput is thus given by:

$$(9) \quad k^* = \left(\frac{As}{n} \right)^{\frac{1}{1-\alpha}} (1-m)^{\gamma}$$

which implies that output per caput in steady-state is given by:

$$(10) \quad y^* = \left(\frac{As}{n} \right)^{\frac{\alpha}{1-\alpha}} (1-m)^{\gamma}$$

Taking logarithms, one obtains an "augmented" Solow equation for the determinants of the steady-state level of per caput GDP:

$$(11) \quad \ln y^* = \frac{\alpha}{1-\alpha} \ln A + \frac{\alpha}{1-\alpha} (\ln s - \ln n) + \gamma \ln(1-m)$$

Linearizing around the steady-state, one obtains the standard convergence specification for the neo-classical growth model:

$$(12) \quad \ln y_t - \ln y_0 = -(1 - \exp\{-\lambda t\}) \ln y_0 + (1 - \exp\{-\lambda t\}) \left(\frac{\alpha}{1-\alpha} \ln A + \frac{\alpha}{1-\alpha} (\ln s - \ln n) + \gamma \ln(1-m) \right)$$

where λ represents the annual rate of convergence. Simple estimations based on equation (12) are presented in Table 2, where the Levine and Renelt (1992) dataset is used.⁷ Again, as with the initial results presented in Table 1, the PFI as well as the DES per caput are both found to be highly significant variables, in this case in logarithmic form within the context of the standard Solow neo-classical model. The estimated annual rate of convergence obtained in these regressions ranges from 0.6 percent in the absence of nutritional variables in the unrestricted specification, to 3 percent in the restricted specification which includes the PFI.

1.5 Non-linearities and threshold effects

It is of course quite possible that the empirical regularity uncovered with the simple linear relationships estimated above hides more complex phenomena linked to threshold effects or non-linearities in the effect of the PFI or the DES per caput on growth. Consider an alternative specification of the regression presented in column (7) of Table 1 in which DES per caput appears in quadratic as well as in linear form. Results for this specification are presented in column (8) of Table 1. It is clear that both the linear and quadratic terms are highly significant at the usual levels of confidence; moreover, the estimated coefficients yield an "inverted-U" relationship between the growth rate of per caput GDP and the DES per caput once decade and continent dummies and a convergence effect are controlled for.

The threshold level of the DES per caput at which the impact of daily calorie intake on growth begins to become negative is equal to 3066 kcal/day. Sixty observations out of the 314 used in the regression presented in column (8) of Table 1 correspond to country-decades with a level of the DES per caput greater than this threshold value. The mean value of per caput GDP for this subsample is equal to US\$ 6 447, whereas the full sample mean is US\$ 1 993.

Figure 5 illustrates the change in the *marginal* impact of the DES per caput, expressed in kcal/day, on the growth rate of per caput GDP, as the marginal impact is evaluated between 1500 and 4000 kcal/day. As shall be seen below, the quadratic specification in the context of the DES per caput variable is often robust to changes in specification or estimation procedure. For the PFI, on the other hand, experimentation revealed that a cubic specification, presented in column (5) of Table 1, offered the best fit to the data. This polynomial form is, however, not robust to the battery of tests that will be presented below. A graphical illustration of the quadratic

⁷ See Levine and Renelt (1992) for the original contribution using this data, as well as Mankiw, Romer and Weil (1992) for the standard assessment of the neoclassical model.

TABLE 2

PFI, DES per caput and economic growth : Augmented Solow model

Method of estimation : OLS (t-statistics below coefficients)

Dependent variable :	(1)	(2)	(3)
growth rate of GDP per caput, 1960-1990			
Intercept	4.775	7.193	-27.576
	3.190	5.435	-2.897
Log of initial GDP per caput	-0.177	-0.492	-0.371
	-1.872	-4.966	-3.306
Log of investment share	3.687	2.154	2.840
	5.681	2.725	3.616
Log of growth rate of population	-0.874	-0.239	-0.469
	-4.392	-1.210	-2.067
Nutritional variables			
Log PFI (%)		-1.264	
		-5.313	
Log DES per caput			4.198
			3.720
Estimated annual rate of convergence (λ)	0.006	0.023	0.015
in unrestricted specification	1.502	3.296	2.317
Estimated annual rate of convergence (λ)	0.010	0.031	0.023
in restricted specification	1.962	3.473	2.679
Estimated capital share (α)	0.601	0.350	0.476
in restricted specification	15.751	3.503	6.270
Mean of dependent variable	2.020	2.029	1.971
Adjusted R^2	0.430	0.596	0.478
σ	1.400	1.187	1.358
Number of observations	100	98	94

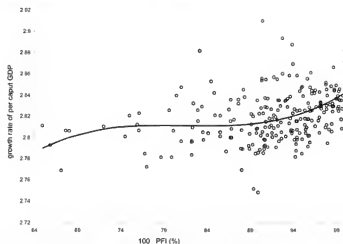
Note: restricted specification corresponds to imposing that the coefficients associated with log investment share and log growth rate of the population are equal and of opposite sign; the restriction is rejected in all cases with an associated p-value that is smaller than 0.001.

Data source: Initial GDP per caput, Summers and Heston (1991); investment share of GDP : World Bank National Accounts; growth rate of population : World Bank Social indicators. Same data as that used by Levine and Renelt (1992); data currently available at: <http://www.worldbank.org/html/prdmg/grthweb/dddevan.htm>.

relationship in terms of the DES per caput is provided by Figure 4, whereas the cubic representation in terms of the PFI is illustrated in Figure 3. Note that the values on the vertical axis in both Figures 3 and 4 are per caput growth rates **net of the values predicted by the regressors** other than nutritional variables. Thus, differences between GDP growth rates in the two figures are due to the different scales in which the variables are measured. The lines in the two figures correspond to the functional forms in which the nutritional variables enter the "chosen" regressions.

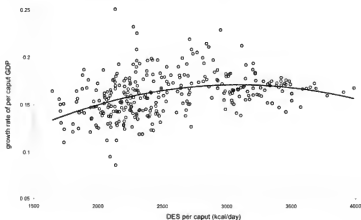
In addition to non-linearities, threshold effects are also a possibility. In columns (7) and (8) of Table 3, estimates are presented corresponding to the inclusion of an interaction term given by the product of the DES per caput by the logarithm of initial GDP per caput (column (8)). In column (7) it is 100 *minus* the PFI that is multiplied by the logarithm of initial GDP per caput. In both cases, the multiplicative term is significant at the usual levels of confidence. In the case of the DES per caput, the value of initial GDP per caput at which the marginal impact of the DES per caput becomes negative is equal to \$US 10 853. For the PFI, on the other hand, there is the somewhat surprising result of a marginal impact of the prevalence of food adequacy increasing with the level of income, indicating that the positive impact on growth of reductions in the PFI is larger at higher levels of income. Interestingly, this result will find some support

FIGURE 3
Impact of the PFI on the growth rate of per caput GDP



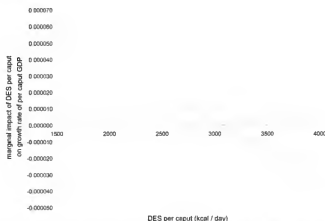
Source: regression 5 of Table 1; vertical axis corresponds to growth rate of GDP per caput, purged of impact of the intercept, two continent dummies, log of initial GDP per caput, and two decade dummies

FIGURE 4
Impact of the DES per caput on the growth rate of per caput GDP



Source: regression 6 of Table 1; vertical axis corresponds to growth rate of GDP per caput, purged of impact of the intercept, two continent dummies, log of initial GDP per caput, and two decade dummies

FIGURE 5
Quadratic specification
Marginal impact of the DES per caput on the growth rate of per caput GDP



Note : computed from the estimates presented in column (8) of Table 1, the solid line corresponds to the point estimate of the marginal impact of the DES per caput on the growth rate of GDP per caput, evaluated between 1500 and 4000 kcal / day ; dotted lines correspond to the one standard-deviation confidence interval around this point estimate.

in the context of the regressions run using the Sachs and Warner (1997a, 1997b) dataset that will be presented below. Both the results in terms of the quadratic specification and those in terms of interaction variables indicate that some form of conditional impact of nutrition on growth is at work. In section 4, this possibility in the context of a switching regression specification will be formally investigated.

TABLE 3
PFI, DES per caput, and economic growth
Controlling for unobserved, country-specific heterogeneity and interaction effects
 (t-statistics below coefficients)

Dependent variable : growth rate of per caput GDP (decade average)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Method of estimation	"within estimator" (country-specific fixed effects)						CLS	
Intercept							0.270	-0.195
							1.717	-3.250
1960s dummy	0.021	0.006	0.008	0.009	0.009	0.006	0.020	0.022
	8.330	2.223	1.918	2.119	2.213	2.140	7.349	7.928
1970s dummy	0.019	0.013	0.013	0.013	0.013	0.013	0.018	0.018
	7.598	4.890	4.314	4.499	4.804	4.699	5.779	6.144
Africa dummy							-0.018	-0.015
							-3.637	-4.042
Latin America dummy							-0.014	-0.016
							-4.510	-4.854
Log of initial GDP per caput (by decade)		-0.026	-0.027	-0.027	-0.032	-0.032	-0.052	0.022
		-4.569	-3.779	-3.824	-4.113	-3.962	-2.184	2.753
Estimated annual rate of convergence (λ)		0.003	0.003	0.003	0.003	0.003		
		4.510	4.515	4.548	5.120	5.006		
Nutritional variables								
100 - PFI (%)			0.001	0.065			-0.002	
			1.717	1.300			-1.495	
(100 - PFI (%)) ²				-8.05E-04				
				-1.312				
(100 - PFI (%)) ³				3.29E-06				
				1.334				
100 - PFI (%) X Log of initial GDP							0.001	
							2.125	
DES per caput (kcal/day)					2.20E-05	4.34E-05	9.19E-05	
					3.227	1.311	4.209	
DES per caput, squared						-4.28E-09		
						-0.655		
DES per caput X Log of initial GDP							-9.89E-06	
							-3.555	
Mean of dependent variable	0.020	0.020	0.020	0.020	0.018	0.018	0.020	0.019
Adjusted R ²	0.483	0.534	0.532	0.532	0.529	0.527	0.331	0.330
α	0.019	0.018	0.018	0.018	0.018	0.018	0.021	0.021
Hausman test : Random effects (H0) vs Fixed effects (H1), p-value	0.000	0.000	0.000	0.000	0.000	0.000	n.a.	n.a.
Number of observations	330	328	320	320	314	314	320	314

Note : each observation corresponds to a country-decade, standard errors are White heteroskedasticity-consistent; threshold value of log GDP per caput in multiplicative specification with DES per caput (column (6)) : 9.29221 (i.e., 10,853 US\$). Data source : same as Table 1.

2. ROBUSTNESS

The recent empirical literature on the determinants of growth is replete with new and original explanations that seek to explain observed differentials in growth performance. Unfortunately, much of this literature is far from being robust, as has been made clear by Levine and Renelt (1992), Sala-i-Martin (1996), and Arcand and Dagenais (1999). Thus, it is important to be cautious regarding results such as those presented in Tables 1 and 2 until it has been established that they are robust to a certain number of standard concerns.

2.1 The Svedberg critique, unobserved, country-specific heterogeneity, and random measurement error

In a recent article, Svedberg (1999) has criticized the procedure followed by the FAO in constructing both measures of the DES per caput and the PFI. Svedberg points out that there are three potential sources of error. First, the DES per caput itself may be measured with error. Second, the parameters of the lognormal distribution that food consumption is assumed to follow (in essence, the coefficient of variation of the distribution, given that its mean is given by the average DES per caput) is assumed to be measured with substantial error (as noted by Svedberg, the lognormal distribution may be an inappropriate assumption in and of itself). Third, the calorie cut-off-point, which defines the threshold below which individuals are assumed to be undernourished may be country specific and it may therefore be inappropriate to assume a common cutoff point of 1.55 or 1.56 the Basic Metabolic Rate (BMR).

In econometric terms there may therefore be two sources of error that plague the nutritional variables included in the regressions presented in Tables 1 and 2. Let the "true" nutritional variable be denoted by X_{it} , where i indexes the country and t indexes the time period (decade). Then the points raised by Svedberg imply that the *observed* value of the nutritional variable, denoted by $\bar{X}_{it}$, is equal to:

$$(13) \quad \bar{X}_{it} = X_{it} + \eta_{it} = X_{it} + \pi_i + \varepsilon_{it},$$

where η_{it} is a composite error term. If the only source of measurement error is given by the country-specific term π_i , then use of the within estimator (country-specific fixed effects) will potentially eliminate all sources of bias and the coefficient associated with the nutritional variable may be estimated consistently. It is likely that this source of error is the dominant one in the PFI estimates given that the parameters of the lognormal distribution used to compute the proportion of the population that is undernourished is assumed to be the same over the three decades for which the figure is reported in the World Food Survey (1996). Moreover, the calorie cutoff point, alluded to above, may also be taken to be a country-specific datum.

If, in addition to the country-specific effect, there is also a country-time specific random shock ε_{it} , then the parameter estimates presented in Tables 1 and 2 are subject to a standard error in variables problem and instrumental variable estimation is called for in order to purge the observed value of the nutritional variable from stochastic elements that will be correlated with the growth regression's disturbance term.

As noted previously, solving the first problem is relatively straightforward, and results corresponding to panel estimation with country-specific fixed effects are presented in the first six columns of Table 3 (see Islam, 1996 for the standard results using panel data in the context of the neo-classical model). As can be seen from the estimates, the coefficients associated with the nutritional variables in columns 3 and 5 (the linear specifications) are robust to the "within"

procedure, although the estimated standard error in the case of the PFI is slightly larger than in the benchmark results presented in Table 1. For the DES per caput, on the other hand, the coefficient increases substantially, from 1.38×10^{-5} in column (7) of Table 1 to 2.20×10^{-5} in column (5) of Table 3. The associated t-statistic remains approximately the same. In terms of country-specific errors in the measurement of the nutritional variables, our results regarding the impact of nutritional concerns are therefore robust to the Svedberg critique.

Several other remarks are in order concerning the "within" estimator results. First, the absolute value of the coefficient associated with the logarithm of initial GDP per caput are much larger (by a factor of ten) once one controls for country-specific fixed effects, and the point estimates are much more precise. This implies that the estimated annual rate of convergence is much greater once country-specific fixed effects are taken into account. Second, the specification in which the PFI enters as a polynomial of degree three is not robust to the inclusion of country-specific fixed effects. The same can be said of the quadratic specification in terms of the DES per caput. Third, a specification involving country-specific random effects is strongly rejected in favour of fixed effects on the basis of the usual Hausman test; in all cases the p-value associated with this test statistic is extremely small.

In contrast to unobserved country-specific heterogeneity, dealing with the second source of bias—random measurement error—is notoriously difficult in the context of growth regressions. This is because, generally speaking, it is extremely problematic to come by admissible exogenous instruments for variables included in the growth regression that should not, in and of themselves, already be included in the equation. One option that is frequently pursued in the literature is to use the initial level of GDP per caput, lagged two periods (two decades, here, see Baltagi, 1996, for the standard treatment). The procedure that is pursued here, in order to eliminate both the country-specific error term and random measurement error involves (i) first-differencing (in order to eliminate π_i) followed by (ii) application of a Generalized Method of Moments (GMM) estimator (in order to eliminate the correlation between the explanatory variables and the equation's disturbance term because of the presence of ε_{it}).⁸ More formally, write the basic growth regression as

$$(14) \quad Y_{it} = \alpha + Z_{it}\beta + \tilde{X}_{it}\gamma + v_{it} = \alpha + Z_{it}\beta + (X_{it} + \pi_i + \varepsilon_{it})\gamma + v_{it}$$

where Y_{it} is the growth rate of GDP per caput of country i at time t ,

Z_{it} is the vector of control variables,

$\tilde{X}_{it}$ is the nutritional variable included in the regression (which is assumed to be measured with error),

α is the constant term, and

β is a vector of parameters associated with the control variables.

The parameter that one wishes to estimate consistently is, of course, γ . In the present context, there are three time periods, corresponding to the three decades for which data are available (1960s, 1970s, 1980s). First differencing the 1980s and the 1970s yields:

$$(15) \quad Y_{i,80} - Y_{i,70} = (Z_{i,80} - Z_{i,70})\beta + (X_{i,80} - X_{i,70})\gamma + (\varepsilon_{i,80} - \varepsilon_{i,70})\gamma + (v_{i,80} - v_{i,70}),$$

⁸ This estimation strategy was first proposed by Arellano and Bond (1991). See Caselli, Esquivel and Lefort (1996) for an application to the growth regressions first presented by Barro and Lee (1994).

TABLE 4

PFI, DES per caput, and economic growth

Sensitivity to data structure : GMM estimation with first-differencing

(t-statistics below coefficients)

Method of estimation	Non-linear least squares				Generalized Method of Moments			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Estimated annual rate of convergence (λ)	0.0066	0.0075	0.0074	0.0058	0.0079	0.0112	0.0141	0.0063
	10.269	11.279	10.824	8.816	7.974	6.086	4.105	6.771
DES per caput (kcal/day)		3.5E-05	7.7E-05			1.4E-04	-1.6E-04	
		3.341	1.477			2.521	-0.512	
DES per caput, squared			-8.0E-09				6.1E-08	
			-0.819				0.938	
PFI (%)				-7.8E-04				-4.7E-03
				-3.412				-2.102
Test of overidentifying restriction (p-value)					0.001	0.259	0.579	0.668
Number of observations	106	102	102	105	103	99	99	102

Note : first difference of observations for the 1980s (t) minus the observations for the 1970s ($t-1$); columns (1) to (4) are estimated by non-linear least squares in order to recover a direct estimate of the annual rate of convergence (λ); in the GMM estimates presented in columns (5) to (8), instruments are the variables themselves for the 1960s ($t-2$), plus the growth rate of GDP per caput for the 1960s; hence, the GMM equations are all overidentified with degree of freedom equal to one. Data source : same as Table 1.

where it should be obvious that π_t has been eliminated. There remains the correlation between ε_{t+1} and ε_{t-1} and v_{t+1} and v_{t-1} . In order to correct for this standard error in variables problem, GMM estimation is applied to equation (15), where the instruments are the variables themselves lagged two periods. That is, the instruments are given by the matrix $W_t = \begin{bmatrix} Y_{t-2} & Z_{t-2} & \tilde{X}_{t-2} \end{bmatrix}$.

Of course, a crucial identifying assumption is also that there is no serial correlation in the error term v_t . The consistency of the resulting GMM estimator is ensured by the standard result due to Hansen (1982). This yields a system that is overidentified with degree of freedom equal to one. The overidentifying restriction can then be tested, using the usual Sargan test in order to assess the validity of the proposed set of instruments.

Results are presented in columns (5) to (8) of Table 4. Keeping in mind that one decade of observations (the 1960s) has been lost due to their use as instruments, it is noteworthy that the estimated impact of the DES per caput (column (6)) increases with respect to the within estimator results presented in column (5) of Table 3 by a factor of seven. The same is true when one considers the results in terms of the PFI (column (8) of Table 4; e.f. column (3) of Table 3), although the coefficient "only" increases by a factor of five. As one would expect, these results suggest that an error in variables problem biases the coefficients presented in Table 3 downwards. In order to isolate the impact of the random error term ε_t from that of π_t , in terms that are strictly comparable, the first 4 columns of Table 4 present results corresponding to first-differencing without resort to GMM estimation. For the linear specification in terms of the DES, accounting for the presence of ε_t through the GMM procedure increases the marginal impact of the nutritional variable by a factor of 4 compared with first-differencing alone (column (2) versus column (6)). For the linear specification in terms of the PFI (columns (4) and (8)), the corresponding figure is 6. None of the specifications including nutritional variables (columns (6), (7) and (8)) are rejected by the test of the overidentifying restriction. Note also that the quadratic specification in terms of the DES per caput is not robust to first-differencing (column (3)) or, for that matter, to first differencing followed by the GMM procedure (column (7)).

Another result of interest involves the estimated annual rate of convergence. Here, it is found that the estimated value of λ (see equation (12) above) is extremely low when compared to the results obtained in the case of the specification based on the Solow model (Table 2) or our benchmark specification (Table 1). This is in sharp contrast to the results presented by Caselli, Esquivel and Lefort (1996) who find that the econometric procedure based on first-differencing and GMM estimation yields estimated annual convergence rates that are *greater* by a factor of ten than those usually reported in the literature (the commonly accepted figure being in the order of 2 percent per year). This difference in results despite the similarity in estimation procedure may be due to the different time-frame considered, since Caselli, Esquivel and Lefort base their results on data spanning five-year periods and, in the context of the neo-classical model, it is often argued that such a time-span is inappropriate.

The upshot is that while Svedberg's (1999) critique of FAO data may indeed be well taken when it comes to assessing the prevalence of food inadequacy or dietary energy supply, his concerns do *not* translate into the disappearance of the statistical significance of the impact of the DES per caput or the PFI on growth. On the contrary, as one would expect on the basis of received econometric theory, controlling for country-specific fixed effects through first-differencing and potential errors in variables through GMM estimation strengthens and amplifies the impact of nutrition on economic growth.

2.2 Sensitivity to data structure

It is possible that the effect of nutritional variables on growth is purely a medium-term phenomenon that is discernible only when high frequency data ("high" in terms of a growth regressions, that is) is used. That this is probably not the case is already suggested by the results presented in Table 2 in terms of the Solow model with data covering a 30 year period. A further manner of assessing this is to compute the "between" estimates, that is, to apply OLS to country averages using our pooled country-decade dataset.

In Table 5, are presented results of re-estimating the basic specification using the between estimator. In this context, the coefficient associated with the PFI (column (1)) remains statistically significant and of the same order of magnitude as in the pooling results presented in Table 1. Inter-decade variations in the PFI are therefore not the source of the statistically significant coefficient associated with the PFI in the growth regressions. The cubic specification (column (2)) is not robust to the "between" procedure, and is therefore present only in our pooling results. Much the same obtains in terms of the DES per caput, although the quadratic specification, which was not robust to the inclusion of country-specific fixed effects, remains robust to the "between" procedure. This points to the conclusion that the threshold effect of the DES per caput on growth is a phenomenon that arises because of country-specific characteristics that are not reflected in our explanatory variables. The Africa dummy variable, for its part, also remains significant, as with the results presented in Table 1.

A second manner of assessing the robustness of our results is to change dataset entirely. It has already been shown that our results hold up in the context of panel estimation where each observation corresponds to a country-decade, as well as when one considers a long-run relationship implied by the Solow model (based on the Levine and Renelt, 1992, dataset). An additional test of robustness is provided by examining the impact of nutritional concerns using the empirical framework proposed by Sachs and Warner (1997a, 1997b) who claim to have identified all of those factors that are fundamental in explaining long run growth. The reader is referred to the original contributions by Sachs and Warner for the justifications behind the inclusion of the various explanatory variables.

TABLE 5
PFI, DES per caput, and economic growth
Sensitivity to data structure (panel data estimation: "between estimator")
(t-statistics below coefficients)

Dependent variable : growth rate of per caput GDP (1960-1990)	(1)	(2)	(3)	(4)
Intercept	-0.090	-1.998	-0.017	-0.178
	-2.690	-0.763	-0.752	-3.681
Africa dummy	-0.013	-0.010	-0.014	-0.014
	-2.706	-1.784	-3.143	-3.156
Latin America dummy	-0.016	-0.011	-0.014	-0.016
	-3.902	-2.296	-3.020	-3.736
Log of initial GDP (by decade)	-0.003	-0.007	-0.001	-0.003
	-1.131	-2.065	-0.345	-0.797
Estimated annual rate of convergence (λ)	3.3E-04	7.0E-04	1.6E-04	3.1E-04
	1.266	2.132	0.487	0.952
Nutritional variables				
100 - PFI (%)	0.001	0.075		
	3.441	0.809		
(100 - PFI (%)) ²		-0.0009		
		-0.853		
(100 - PFI (%)) ³		3.81E-06		
		0.910		
DES per caput (kcal/day)			1.17E-05	1.44E-04
			1.802	3.985
DES per caput, squared				-2.40E-08
				-3.7143
Mean of dependent variable	0.019	0.019	0.018	0.018
Adjusted R ²	0.362	0.373	0.332	0.407
σ	0.016	0.016	0.016	0.015
Number of observations	110	110	108	108

Note : standard errors are White heteroskedasticity-consistent; threshold value of DES per caput in quadratic specification (column (4)) : 3000 kcal/day. Data source : same as Table 1.

Results are presented in Table 6, and they confirm our previous findings. First, the impact of the DES per caput (see column (2) of Table 6) on the growth rate of GDP per caput is of the same order of magnitude as in our benchmark results presented in Table 1 (note that, in Table 1, the dependent variable is expressed in decimal terms, i.e., a growth rate of 2 percent is expressed as 0.02, whereas, in the Sachs-Warner dataset, the same growth rate appears as 2), although it is only marginally significant. Second, the PFI, when entered in logistic form, is highly significant (corresponding t-statistic of 4.592). If γ denotes the coefficient associated with the PFI, the logistic specification implies that the marginal impact of an increase of the PFI on the growth rate of per caput GDP is equal to:

$$(16) \quad \frac{\partial}{\partial PFI} GROWTH = -\gamma \frac{\exp\{PFI\}}{[1 + \exp\{PFI\}]^2}.$$

Estimated at the sample mean (PFI = 5.72%), this implies that a decrease of 1 percent in the PFI increases the growth rate of GDP per caput by 0.014 percentage points. For countries with a PFI of one percent, the corresponding figure for the total elimination of food inadequacy is

TABLE 6
PFI, DES per caput, and economic growth
Sensitivity to data structure : Sachs-Warner (1997) dataset
 (t-statistics below coefficients)

Dependent variable : growth rate of per caput GDP (1960-1990)	(1)	(2)	(3)
Intercept	-68.470	-77.195	-101.058
	-1.748	-1.937	-2.840
Log of real GDP per economically active inhabitant in 1965	-1.523	-1.585	-1.518
	-6.421	-6.491	-7.222
Openness times log GDP per ea. in 1965	-1.105	-1.070	-1.086
	-3.095	-2.949	-3.421
Openness to international trade (share of years open 1965-90)	11.102	10.767	10.553
	3.771	3.607	4.032
Landlocked dummy variable	-0.607	-0.579	-0.506
	-2.405	-2.290	-2.262
Log life expectancy circa 1970	37.986	42.303	55.413
	1.900	2.082	3.047
Square of log life expectancy	-4.419	-5.041	-6.780
	-1.729	-1.938	-2.907
Central government savings, 1970-90	0.114	0.113	0.115
	5.124	5.021	5.854
Dummy for tropical climate	-0.875	-0.665	-0.180
	-2.996	-1.994	-0.581
Institutional quality index	0.319	0.306	0.241
	3.837	3.506	3.075
Natural resource exports / GDP 1970	-4.022	-4.000	-3.454
	-4.040	-3.989	-3.886
Growth in ea. pop - pop growth	0.945	0.977	1.018
	2.621	2.707	3.196
Nutritional variables			
DES per caput (kcal/day)		0.001	
		1.717	
$1/(1+\exp(\text{PFI}))$			4.370
			4.562
Mean of dep. var	1.798	1.791	1.810
Adjusted R^2	0.837	0.842	0.874
σ	0.774	0.773	0.883
Number of observations	82	79	81

Note: Sachs and Warner (1997) dataset currently available at http://www.ksg.harvard.edu/cid/cid_public_data.htm. See aforementioned http for details concerning the sources of the data and the definition of the variables. Method of estimation : OLS.

0.85 percentage points of additional growth. Needless to say, the latter is an exceedingly large number, especially since the mean value of the growth rate of GDP per caput in the dataset is equal to 1.81 percent, and it reflects the functional assumption that the marginal gains in terms of growth stemming from reductions in the PFI increase as the PFI decreases.

An interesting corollary to these results is that the dummy variable associated with a tropical climate becomes statistically insignificant. This suggests that the tropical climate dummy, in Sachs and Warner's results, is simply proxying for climatically-determined differences in nutritional requirements. Moreover, the coefficients associated with the life expectancy variables become both larger and more significant, indicating potentially interesting interaction effects between nutrition and life expectancy which will be explored at greater length below.

While the empirical analysis presented in Tables 1 to 6 highlights that nutritional status does appear to affect the growth rate of GDP per caput and the simple theoretical models proposed show that it is relatively straightforward to include malnutrition within the context of the usual theoretical constructs, it does not tell us how this impact obtains. In other words, the interesting question is the following : what is the mechanism through which nutritional status affects economic growth ? In what follows, those mechanisms are examined that provide the most likely explanations for the correlations presented above and subject them to formal econometric analysis motivated by solid theoretical foundations.

3. TRANSMISSION MECHANISMS

There are several transmission mechanisms through which malnutrition could affect growth. A *direct* transmission mechanism has already been identified in the context of the simple theoretical models presented above: the productivity of the labour force operating through the efficiency effect of increased levels of nutrition. Before examining two *indirect* transmission mechanisms, a general framework is proposed that will facilitate the interpretation of the econometric results that will be presented below. Essentially, the empirical issue will be to disentangle direct from indirect effects of malnutrition on growth. Regression analysis is, of course, ideally suited to this exercise.

3.1 Direct versus indirect transmission mechanisms

Consider a simple specification of a growth equation where the growth rate of per caput GDP (*GROWTH*) is a function of some "intermediate" variable x , a set of control variables, y , and a nutritional variable, denoted by m ; thus:

$$(17) \quad GROWTH = \phi(y, x, m)$$

Suppose now that the "intermediate" variable is, in turn, a function of the nutritional variable. This can be expressed by posing:

$$(18) \quad x = x(m)$$

Substituting equation (18) into equation (17) yields:

$$(19) \quad GROWTH = \phi(y, x(m), m) = \phi(y, m)$$

Consider the total derivative of this last expression (equation (19)) with respect to m . One obtains:

$$(20) \quad \frac{d}{dm} GROWTH = \frac{\partial \phi(y, x(m), m)}{\partial x} \frac{dx(m)}{dm} + \frac{\partial \phi(y, x(m), m)}{\partial m}$$

Empirically, the implication is clear. If a regression of the growth rate is run on m , the estimated coefficient associated with this last variable gives us the value of the *total* derivative of growth with respect to m . In other words, the coefficient associated with m is equal to equation (20). It follows that a statistically significant coefficient associated with the DES per caput or the PFI can obtain for three reasons:

- i. there is a direct relationship between growth and malnutrition but no indirect link, i.e.,

$$\frac{\partial \phi(y, x(m), m)}{\partial m} \neq 0 \quad \text{and} \quad \frac{\partial \phi(y, x(m), m)}{\partial x} \frac{dx(m)}{dm} = 0;$$

- ii. there is an indirect relationship between growth and malnutrition but no direct effect, i.e.,

$$\frac{\partial \phi(y, x(m), m)}{\partial m} = 0 \quad \text{and} \quad \frac{\partial \phi(y, x(m), m)}{\partial x} \frac{dx(m)}{dm} \neq 0;$$

iii. both (i) and (ii) obtain.⁹

In order to distinguish between direct and indirect transmission mechanisms, the reduced form regression given by equation (19) is first run. As seen above in the results presented in Tables 1 to 6, the coefficient associated with the nutritional variable is indeed statistically significant. In order to test for whether this effect is associated with a direct or an indirect impact of malnutrition on growth, the “intermediate” variable is then introduced into the regression. Essentially, the regression given by equation (17) is run. If the coefficient associated with the intermediate variable is statistically significant and the coefficient associated with the DES per caput or the PFI becomes statistically insignificant (or, at least, falls in a statistically significant manner), it follows that there is an indirect impact of malnutrition on growth that is mediated by the intermediate variable. If it remains statistically significant, both a direct and an indirect effect of malnutrition on growth are at work.¹⁰

In what follows, a first assessment is presented of the potential role played by two transmission mechanisms through which nutritional concerns may impact the growth rate of GDP per caput indirectly. The two transmissions mechanisms in question are life expectancy, which has been shown by a number of authors (e.g., Barro and Lee, 1993, Sachs and Warner, 1997a, 1997b) to be a significant determinant of growth, and schooling, which has been the focus of intense empirical research since the original contribution, based on an augmented Solow model, by Mankiw, Romer and Weil (1992).

3.2 Life expectancy

As has already been seen, in the context of the empirical results based on the Sachs and Warner (1997) dataset, both life expectancy and nutritional variables are statistically significant when entered into a long-run growth regression based on thirty year averages. The question is whether this result will hold up within the context of our pooled country-decade dataset.

Empirical results concerning life expectancy based on the same dataset as that used in the results presented in Tables 1, 3, 4 and 5 are presented in Table 7. Given our previous findings using both the between and the within estimator, three sets of results are presented, corresponding to pooled time-series cross section (columns (1), (4) and (7)), OLS on country means (columns (2), (5) and (8)), and panel estimation which controls for country-specific fixed effects (columns (3), (6) and (9)). The results are particularly revealing.

First, the coefficient associated with life expectancy is statistically significant at the usual levels of confidence in those six cases in which either pooling or the between estimator is applied, while its effect vanishes once country-specific fixed effects are controlled for. Second, the coefficient associated with the PFI is statistically significant in all three methods of estimation. Third, the coefficient associated with the DES per caput in the linear specification becomes statistically insignificant in the pooling and between results, but is highly significant when one controls for country-specific fixed effects. Fourth, and in contrast to the linear specification, the DES per caput and the DES per caput squared are significant determinants of growth in the pooling and between results, but vanish almost entirely when one uses the within procedure.

⁹ Of course, the absence of a statistically significant coefficient associated with the nutritional variable in the reduced form regression could obtain because the two terms on the right-hand-side of equation (20) are of opposite sign and simply cancel out.

¹⁰ This line of reasoning is explained at greater length in Arcand, Guillaumont and Guillaumont Jeanneney (2000) in terms of Montecarlo-based simulations, though the basic intuition should be obvious.

TABLE 7
PFI, DES per caput, and economic growth
Transmission mechanisms : life expectancy
(t-statistics below coefficients)

Dependent variable: growth rate of per caput GDP									
Method of estimation									
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	OLS	between	within	OLS	between	within	OLS	between	within
Intercept	-0.048	-0.071		-0.002	-0.020		-0.104	-0.141	
	-2.367	-2.091		-0.149	-0.900		-3.745	-3.045	
1960s dummy	0.024		0.007	0.025		0.006	0.024		0.005
	9.200		0.885	9.465		0.737	9.269		0.655
1970s dummy	0.019		0.012	0.020		0.012	0.019		0.012
	6.601		3.331	6.961		3.409	6.731		3.267
Africa dummy	-0.006	-0.005		-0.007	-0.007		-0.008	-0.007	
	-1.351	-0.932		-1.667	-1.258		-1.941	-1.479	
Latin America dummy	-0.015	-0.015		-0.015	-0.016		-0.016	-0.016	
	-5.332	-3.733		-4.580	-3.647		-5.304	-4.138	
Log of initial GDP (by decade)	-0.010	-0.009	-0.026	-0.010	-0.007	-0.033	-0.010	-0.007	-0.033
	-3.714	-2.702	-3.914	-3.312	-1.788	-4.325	-3.385	-2.026	-4.155
Life expectancy at age zero	0.001	0.001	0.000	0.001	0.001	-0.001	0.001	0.001	-0.001
	4.467	3.241	-0.254	4.321	3.460	-0.476	4.045	3.094	-0.544
Nutritional variables									
100 - PFI (%)	0.001	0.001	0.001						
	2.937	2.073	2.167						
DES per caput (kcal/day)				4.61E-06	1.40E-07	2.41E-05	8.80E-05	1.03E-04	5.29E-05
				1.134	0.021	3.286	4.444	2.907	1.521
DES per caput, squared							-1.53E-08	-1.64E-06	-5.72E-09
							-4.361	-2.949	-0.852
Mean of dependent variable	0.019	0.018	0.019	0.018	0.018	0.018	0.018	0.018	0.018
Adjusted R ²	0.392	0.432	0.540	0.367	0.389	0.547	0.391	0.436	0.546
σ^2	0.019	0.014	0.017	0.020	0.014	0.017	0.019	0.014	0.017
Hausman test : Random effects (H0) vs Fixed effects (H1), p-value			0.040			0.001			0.007
Number of observations	292	100	292	291	100	291	291	100	291

Note : standard errors are White heteroskedasticity-consistent; threshold value of DES per caput in quadratic specifications where coefficients are statistically significant (columns (7) and (8)) : 2875 and 2798 kcal/day, respectively. Data source: Life expectancy at age zero : Barro and Lee (1993).

Fifth, a specification in terms of country-specific random effects is soundly rejected by the usual Hausman test in favour of the fixed-effects specification in all cases.

The contrast with the results obtained using the Sachs-Warner dataset are striking. In the long run, or when using either pooling or the between estimator, the impact of life expectancy on growth is statistically significant, but this effect disappears when one uses the within estimator. This suggests that the impact of life expectancy on growth is essentially a long-run phenomenon, and that its impact on growth obtains because it is controlling for other, unobserved, country characteristics that are purged once fixed effects are included. This disappearance of what was otherwise a highly significant variable is typical of results using panel data with country-specific fixed effects. The PFI results are encouraging in that they imply that there is a statistically significant impact of malnutrition on growth irrespective of the time frame of analysis. Since life expectancy is included in the three regressions reported in columns (1), (2) and (3), it follows (based on the analytical framework outlined above) that there is a direct impact of the PFI on the growth rate of GDP per caput.

In contrast to the results based on the PFI, our results for the DES per caput suggest : (i) that in the long run (i.e., using the between estimator), the impact of the DES per caput on growth obtains indirectly through its effect on life expectancy; and (ii) that in the medium run, and when one accounts for unobserved country-specific heterogeneity, there is a direct impact of the DES per caput on growth that is not mediated through life expectancy.

A potential solution to the paradox regarding the low rate of growth of SSA also appears in the results presented in Table 7. This is because, in contrast to our earlier results, the magnitude of the coefficient associated with the SSA dummy variable is halved when life expectancy is included in the regression and it is marginally significant at the usual levels of confidence (one exception to this is given by the quadratic specification presented in column (7), where the associated t-statistic is equal to -1.941). This is in sharp contrast to the usual results reported in the literature concerning African growth (e.g. Easterly and Levine, 1997), where the dummy variable remains highly significant. This result, it should be obvious from our results that include nutritional variables, is robust to the inclusion of the PFI or the DES per caput. Alternative explanations for the poor growth performance of SSA, such as those based on the high degree of ethnolinguistic fragmentation of the continent, never allow one to "kill the dummy".

3.3 Schooling

Since the appearance of Lucas's (1988) seminal article on learning or doing, the importance of human capital in the growth process has been intensely studied by economists. Mankiw, Romer and Weil (1992) constitutes the best-known quantitative assessment of the validity of the augmented Solow model in which human capital enters the production as a complementary factor input.

Empirical results corresponding to the hypothesis that schooling is one of the transmission mechanisms through which nutritional concerns impact the growth rate of GDP per caput are presented in Table 8. As with the case of life expectancy, results are presented based on simple pooled estimation, the between estimator, and the within estimator which controls for country-specific fixed effects. The results are similar to those in the case of life expectancy, although a number of specificities emerge.

First, the coefficient associated with schooling is generally statistically significant in the basic pooled regression results (columns (1), (4) and (7)), and its standard error increases when one moves to results based on the between estimator (columns (2), (5) and (8)); it becomes negative, though statistically indistinguishable from zero, once the within estimator results are considered (columns (3), (6) and (9)). This result is well-known in the context of panel growth regressions which control for unobserved country-specific effects, and it is sometimes seen as something of a puzzle. It should not be. Indeed, as noted by Barro and Lee (1993), the neo-classical growth model would predict, in its closed economy form, a negative and statistically significant coefficient on schooling (the initial level of schooling, that is), just as one expects a negative coefficient on the initial level of GDP per caput if convergence effects are present. As they put it : "if there are diminishing returns to reproducible factors, as in the usual neo-classical growth model for a closed economy..., then an equiproportionate increase in [initial GDP per caput, initial schooling, and initial life expectancy] would reduce [the growth rate of per caput GDP]." (p. 274).

In this context, it is interesting to note that Barro and Lee (1993) themselves, when considering a panel regression using 3SLS over two decades in which male and female schooling appear separately, find a negative and statistically significant coefficient associated with female

TABLE 8
PFI, DES per caput, and economic growth
Transmission mechanisms: schooling

(t-statistics below coefficients)

Dependent variable	(1)		(2)		(3)		(4)		(5)		(6)		(7)		(8)		(9)	
growth rate of per caput GDP	OLS		between		within		OLS		between		within		OLS		between		within	
Method of estimation	OLS		GMM		GMM		OLS		GMM		GMM		OLS		GMM		GMM	
Intercept	-0.091	-0.113	-3.522	-2.620	0.017	1.034	0.021	0.831	-0.154	-4.861	-0.199	-3.486						
1960s dummy	0.021	0.007	0.023	0.006	0.022	0.006	0.022	0.006	0.022	0.006	0.022	0.007					0.007	
1970s dummy	7.275	1.174	8.022	1.296	7.848	1.253	0.017	0.011	0.020	0.012	0.019	0.012					0.012	
1970s dummy	5.162	2.979	6.170	3.367	5.787	3.179												
Africa dummy	-0.011	-0.011	-0.013	-0.013	-0.013	-0.013	-0.013	-0.013	-0.013	-0.013	-0.013	-0.013						
Latin America dummy	-2.423	-2.153	-3.116	-2.355	-3.409	-2.579	-0.014	-0.014	-0.014	-0.014	-0.016	-0.017						
Log of initial GDP (by decade)	-5.005	-3.370	-4.342	-3.009	-5.178	-3.776	-0.006	-0.006	-0.022	-0.006	-0.005	-0.025	-0.007	-0.007	-0.007	-0.023	-2.651	-0.013
Log schooling	-2.411	-1.719	-2.694	-1.865	-1.147	-2.810	0.006	0.006	-0.011	0.010	0.012	-0.013	0.010	0.010	0.010	-0.013	-1.107	-0.013
	1.972	1.123	-0.957	2.719	2.050	-1.163												
Nutritional variables																		
100 - PFI (%)	0.002	0.002	0.001															
	5.383	3.924	2.449															
DES per caput (kcal/day)							1.04E-05	9.25E-06	1.94E-05	1.46E-04	1.84E-04	7.69E-05						
							2.411	1.258	2.583	6.484	4.394	2.238						
DES per caput, squared										-2.46E-08	-3.14E-08	-1.14E-08						
										-8.075	-4.22721	-1.7037						
Mean of dependent variable	0.021	0.020	0.021	0.020	0.019	0.020	0.019	0.020	0.020	0.020	0.019	0.020						
Adjusted R ²	0.383	0.416	0.590	0.333	0.329	0.584	0.390	0.440	0.588	0.390	0.440	0.588						
F	0.020	0.015	0.016	0.021	0.016	0.016	0.016	0.016	0.016	0.020	0.015	0.016						
Hausman test: Random effects (H0) vs Fixed effects (H1), p-value				0.000					0.027								0.046	
Number of observations	261	94	261	258	93	258	258	93	258	258	93	258						

Note: standard errors are White heteroskedasticity-consistent; threshold value of DES per caput in quadratic specification where coefficients are statistically significant (columns (7) and (8)): 2967 and 2929 kcal/day, respectively. Data source: Lo of 1 + average years of school attainment, quinquennial values (1960-65, 1970-75, and 1980-85): Barro and Lee (1993).

schooling, which they ascribe to "less female [schooling] attainment [signifying] more backwardness and accordingly higher growth potential through the convergence mechanism." (p. 277). Be this as it may, it will be seen below that the coefficient associated with schooling is negative and statistically significant when it is endogenized within the context of GMM estimation.

The second result presented in Table 8 that is worthy of mention is that the PFI is statistically significant in all three specifications in which it appears ((columns (1), (2) and (3)). Since schooling is included in all three regressions, it follows that, as with life expectancy, there is a direct impact of the PFI on growth that is not mediated through its impact on schooling. In fact, compared with the results presented in column (3) of Table 3 (within estimation of the same equation without including schooling), the impact of the PFI on the growth rate of GDP is of the same order of magnitude and is estimated more precisely. In the case of the DES per caput, much the same obtains. The associated coefficient remains statistically significant in the pooling results, and does so in the context of "within" estimation as well (the coefficient is of the same order of magnitude as that presented in column (5) of Table 3). As with life expectancy, the quadratic specification with respect to the DES per caput remains robust to the inclusion of

schooling for the pooling and between results, while the coefficients are estimated less precisely once one moves to country-specific fixed effects. In contrast to the results based on life expectancy, it is interesting to note that the SSA dummy remains statistically significant, indicating that it is differences in terms of life expectancy that explain the slow growth of SSA economies, while differences in schooling do not.

These results imply that there is a potentially interesting story regarding life expectancy as a transmission mechanism whereby nutritional concerns indirectly affect the growth rate of GDP per caput, although it is clear that the direct impact of nutritional variables on growth through their effect on the productivity of labour will remain important since the fall in the coefficient associated with the DES per caput or the PFI when schooling or life expectancy are introduced into the equation is negligible. In the case of schooling as a transmission mechanism, on the other hand, the results are less promising. Disentangling the contribution of the indirect impact from the direct impact of nutritional variables on growth will be dealt with at greater length below in the context of the estimation of structural model by instrumental variable techniques.

4. CONDITIONAL RESPONSE

The simple theoretical constructs presented in section 1 in order to account for the statistical significance of nutritional variables in the simple growth regressions suffer, of course, from the assumption of exogeneity, in the sense that the impact of malnutrition on growth is not modelled explicitly within the theoretical model. In what follows, a simple endogenous growth model is constructed in which the productivity of labour depends on consumption, and in which nutritional growth traps can endogenously arise. This theoretical model is then used as the basis for an empirical procedure in which the response of growth to nutritional concerns is conditional on the nutritional status of the population.

4.1 Nutritional growth traps ?

Consider the simple AK model sketched in section 1 above. Let effective labour input be specified as:

$$(21) \quad \tilde{L}_t = \begin{cases} \exp\{\gamma(c_t - \bar{c})\} L, & c_t < \bar{c} \\ L & \text{otherwise.} \end{cases}$$

This formulation implies that effective labour input is an increasing function of consumption for $c_t < \bar{c}$, whereas, once a minimal level of consumption is attained (denoted here by $\bar{c}$), the usual dynamics of the AK model take over. It is worth noting that this formulation is more faithful to the notion of nutritional efficiency wage effects than the simple *ad hoc* formulation presented in section 1, since the productivity of labour, via the efficiency impact of consumption, is endogenously determined within the model.

With this parameterization, the dynamics of capital are given by:

$$\dot{K}_t = A e^{\gamma(c_t - \bar{c})} K_t - c_t.$$

The corresponding Hamiltonian is therefore given by:

$$(22) \quad H_t = \frac{c_t^{1-\sigma}}{1-\sigma} e^{-\rho t} + \mu_t (A e^{\gamma(c_t - \bar{c})} K_t - c_t).$$

By an application of Pontryagin's Maximum Principle, the necessary conditions for an optimum are given by:

$$(23) \quad \frac{\partial H_t}{\partial c_t} = 0 \Rightarrow c_t^{-\sigma} e^{-\rho t} + \mu_t (\gamma A e^{\gamma(c_t - \bar{c})} K_t - 1) = 0;$$

$$(24) \quad \frac{\partial H_t}{\partial K_t} = -\dot{\mu}_t \Rightarrow \mu_t A e^{\gamma(c_t - \bar{c})} = -\dot{\mu}_t;$$

plus the usual transversality condition. From the first condition, the solution for the costate variable is:

$$(25) \quad \mu_t = \frac{c_t^{-\sigma} e^{-\rho t}}{1 - \gamma A e^{\gamma(c_t - \bar{c})} K_t}.$$

Taking its derivative with respect to time, the following expression results:

$$\dot{\mu}_t = \frac{(-\sigma \dot{c}_t c_t^{-\sigma-1} e^{-\rho t} - \rho c_t^{-\sigma} e^{-\rho t})(1 - \gamma A e^{\gamma(c_t - \bar{c})} K_t) + (\gamma \dot{c}_t A e^{\gamma(c_t - \bar{c})} K_t + \gamma A e^{\gamma(c_t - \bar{c})} \dot{K}_t) c_t^{-\sigma} e^{-\rho t}}{(1 - \gamma A e^{\gamma(c_t - \bar{c})} K_t)^2}.$$

After some manipulations, this can be rewritten as:

$$(26) \quad \frac{\dot{\mu}_t}{\mu_t} = \frac{(-\sigma \dot{c}_t c_t^{-1} - \rho)(1 - \gamma A e^{\gamma(c_t - \bar{c})} K_t) + (\gamma \dot{c}_t K_t + \dot{K}_t) \gamma A e^{\gamma(c_t - \bar{c})}}{1 - \gamma A e^{\gamma(c_t - \bar{c})} K_t}.$$

Now from the second condition, another expression can be obtained for the growth rate of the costate variable. Equating the two expressions allows the following expression:

$$\dot{c}_t = \frac{(1 - \gamma c_t) A e^{\gamma(c_t - \bar{c})} - \rho(1 - \gamma A e^{\gamma(c_t - \bar{c})} K_t)}{\sigma c_t^{-1} (1 - \gamma A e^{\gamma(c_t - \bar{c})} K_t) - \gamma^2 A e^{\gamma(c_t - \bar{c})} K_t}.$$

The laws of motion of the system are therefore given by:

$$(27) \quad \frac{\dot{c}_t}{c_t} = \frac{(1 + \gamma(\rho K_t - c_t)) A e^{\gamma(c_t - \bar{c})} - \rho}{\sigma - (\sigma + \gamma c_t) \gamma A e^{\gamma(c_t - \bar{c})} K_t}.$$

$$(28) \quad \frac{\dot{K}_t}{K_t} = A e^{\gamma(c_t - \bar{c})} - \frac{c_t}{K_t}.$$

Notice that, for $\gamma = 0$, the usual expression of a constant (positive) growth rate of consumption (see equation (27)) can be obtained. The question is, of course, whether the dynamics of the system will allow the economy to reach the level of consumption at which $c_t = \bar{c}$ at which point the usual growth dynamics of the AK model take over.

Consider the equation that governs the dynamics of consumption. Then it is clear that to reach a situation where $c_t = \bar{c}$, it must be the case that:

$$\frac{(1 + \gamma(\rho K_t - c_t)) A e^{\gamma(c_t - \bar{c})} - \rho}{\sigma - (\sigma + \gamma c_t) \gamma A e^{\gamma(c_t - \bar{c})} K_t} > 0.$$

For both the numerator and the denominator of this expression to be negative (the other possibility being that they are both positive), it must be the case that:

$$(29) \quad \frac{\sigma}{(\sigma + \gamma c_t) \gamma A e^{\gamma(c_t - \bar{c})}} < K_t < \frac{\rho + (\gamma c_t - 1) A e^{\gamma(c_t - \bar{c})}}{\gamma \rho A e^{\gamma(c_t - \bar{c})}}.$$

The question then is whether such an interval exists, which boils down to whether the inequality:

$$(30) \quad \sigma \rho < \sigma \rho + \rho \gamma c_t + (\sigma + \gamma c_t)(\gamma c_t - 1) A e^{\gamma(c_t - \bar{c})}$$

can hold. For very low initial levels of consumption, which corresponds empirically to a large shortfall of c_t with respect to $\bar{c}$, one can write, evaluating the preceding expression at $c_t = 0$, $\sigma p < \sigma p - \sigma A e^{-\gamma \bar{c}}$ which of course cannot hold. It follows that it is quite possible, for low initial levels of consumption, which correspond to a very high PFI or a very low DES per caput, that the growth rate of consumption will be negative and that the economy will remain in an "undernourishment growth trap".

What are the empirical implications of the presence of nutritional growth traps? *A priori*, the most probable manner in which one can identify a country subject to a nutritional growth trap is in terms of the *absence* of convergence effects. While a standard growth model yields a convergence equation in which the subsequent rate of growth is a decreasing function of the initial level of GDP per caput (see equation (12)), one would expect, for a country caught in a growth trap, that such an effect would not obtain, meaning that the coefficient associated with initial GDP per caput should be statistically indistinguishable from zero in a growth regression. In addition, it is for countries caught in a nutritional growth trap that the impact of the DES per caput is most likely to be felt. Moreover, it is clear from the theoretical model presented above, that for a country with a level of consumption outside of the range in which the growth trap effect operates (in terms of the model, this means that in such countries $c_t > \bar{c}$), that there should be *no* impact of the DES per caput on the productivity of labour. The DES per caput should therefore be excluded from the growth regression corresponding to such countries. These exclusion restrictions will constitute the basis for the empirical implementation pursued in what follows.

4.2 Empirical specification

In order to test for the presence of nutritional growth traps in a manner that corresponds to the theoretical arguments enunciated above, we turn to a switching regression specification in which regime 1 corresponds to a "high PFI" scenario and regime 2 corresponds to a "low PFI" scenario. Whether a country belongs to regime 1 or regime 2 will depend simultaneously upon its income per caput and its PFI.

Let x_i ($i = 1, \dots, N$, indexes observations) denote the $N \times 5$ matrix of control variables that is common to both regimes (a constant term, two decade dummies, and two continent dummies). Let $x_{1i} = [x_i, DES_i]$ denote the $N \times 6$ matrix of explanatory variables that correspond to the high PFI regime and $x_{2i} = [x_i, \log GDP/capita, \log Schooling]$ denote the $N \times 7$ matrix of explanatory variables that corresponds to the low PFI regime; the dependent variable (the annual growth rate of per caput GDP) will be denoted by y_i with y_{1i} denoting the growth rate under the high PFI regime and y_{2i} denoting the growth rate under low PFI regime. The econometric specification is then given by the following system of equations:

$$(31) \quad \begin{aligned} \text{High PFI regime} : y_{1i} &= \beta_1' x_{1i} + u_{1i} \\ \text{Low PFI regime} : y_{2i} &= \beta_2' x_{2i} + u_{2i} \end{aligned}$$

where the choice between regimes is given by the following sorting condition:

$$(32) \quad y_i = \begin{cases} y_{1i} & \text{if } \gamma' z_i + v_i < 0 \\ y_{2i} & \text{if } \gamma' z_i + v_i \geq 0 \end{cases}$$

with $v_i \sim N(0, 1)$, and where z_i is an $N \times 3$ matrix constituted by a constant term, the logarithm of GDP per caput, and the logarithm of the PFI. The distributional assumptions on the disturbance terms in the two regimes are given by $(u_{1i}, u_{2i}) \sim N(0, 0, \Sigma)$ where:

$$(33) \quad \Sigma = \begin{bmatrix} \sigma_1^2 & \sigma_{12} \\ \sigma_{12} & \sigma_2^2 \end{bmatrix}.$$

It is well known (e.g., Maddala (1983), Quandt (1988)) in the context of this type of model that the off-diagonal term σ_{12} is not identifiable (for the simple reason that both regimes cannot simultaneously obtain). Note that, for identification purposes (Maddala and Nelson (1975), p. 424), it is necessary to (i) normalize the standard deviation of the selection equation such that it is equal to one (that is why v_i is distributed $N(0,1)$ and not $N(\mu, \sigma^2)$) and (ii) normalize the coefficient on the constant term in the selection equation to one (i.e., the parameters in the selection equation are only identified up to a multiplicative constant).

The selection equation which determines whether a country belongs to the high PFI regime or the low PFI regime is given by a (latent) regime indicator function defined as follows:

$$(34) \quad I_i(z_i) = \begin{cases} 1 & \text{if } \gamma' z_i + v_i < 0 \\ 0 & \text{if } \gamma' z_i + v_i \geq 0 \end{cases}$$

Therefore the left-hand-side variable from the growth equations can be written in the following form:

$$(35) \quad y_i = I_i(z_i) \beta_1' x_{0i} + (1 - I_i(z_i)) \beta_2' x_{2i} + I_i(z_i) u_{0i} + (1 - I_i(z_i)) u_{2i},$$

where $I_i(z_i)$ is approximated in continuous form by the probit function:

$$(36) \quad \hat{I}_i(z_i) = \int_{-\infty}^{\gamma' z_i} \left(\frac{\exp\{-v^2/2\}}{\sqrt{2\pi}} \right) dv.$$

One can then easily construct the corresponding likelihood function and maximize it with respect to $\beta_1, \beta_2, \sigma_1, \sigma_2, \gamma$ which, owing to the above normalizations, are all identifiable. Note that this procedure does not arbitrarily assign an observation to a given regime: this process is carried out optimally through the maximization of the likelihood function, thus allowing the data (conditioned by the variables included in the selection equation) to sort themselves freely into the two regimes.

Results are presented in Table 9. As is obvious from the estimated coefficients, sample separation based on the logarithm of initial GDP per caput and the PFI is crisp, with the associated coefficients estimated quite precisely. The sample separation based on initial GDP per caput and the PFI is illustrated graphically in Figure 6.

In the low PFI regime, convergence effects are strong, and the logarithm of schooling appears with the usual positive, and statistically significant coefficient. In the high PFI regime, on the other hand, the coefficient associated with the DES per caput is equal to 2.56×10^{-3} , of similar order of magnitude to that obtained in column (4) of Table 8 which corresponds to the simple pooling results that include schooling. Here, the coefficient is twice as large, which is to be expected given that it is estimated only on those observations which the maximum likelihood procedure classified as belonging to the high PFI regime.

Perhaps the most comforting result is that the mean value of the growth rate of GDP per caput for those countries classified as belonging to the low PFI regime (0.030) is almost three

TABLE 9

Nutritional growth traps ?

Estimation of a two-regime (high PFI, low PFI) switching regression model with unknown sample separation

(t-statistics below coefficients)

	(1)	(2)
Selection equation		
Log of initial GDP (by decade)	0.300	0.297
	3.924	3.652
PFI (%)	-0.268	-0.266
	-4.618	-4.214
Growth equation		
	Low PFI regime	High PFI regime
Intercept	0.184	-0.053
	5.771	-2.718
1960s dummy	0.014	0.025
	2.891	5.663
1970s dummy	0.019	0.017
	4.697	4.186
Africa dummy	0.033	-0.010
	1.501	-2.203
Latin America dummy	-0.019	-0.013
	-4.775	-2.340
Log of initial GDP (by decade)	-0.023	-0.023
	-5.083	-4.938
Log schooling	0.019	0.018
	3.018	2.865
DES per caput (kcal/day)		
	2.56E-05	2.59E-05
	3.208	2.852
Mean of dependent variable for regime	0.0300	0.0119
Average estimated probability of belonging to regime	0.459	0.540
σ	0.017	0.015
	14.294	12.053
Log likelihood	-650.458	-650.511
Number of observations	251	251

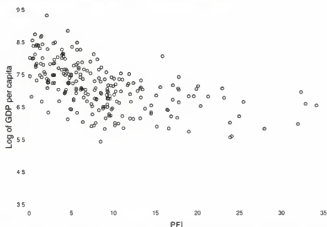
Note : estimated by Maximum Likelihood. Data source : same as Table 8.

times as large as the mean value of the growth rate of those countries classified as belonging to the high PFI regime (0.012), as one would expect if the underlying theoretical model is an adequate representation of reality. Finally, note that the theoretically motivated assumption that there are no convergence effects in the regime associated with a nutritional growth trap is supported by the results presented in the second part of Table 9 (system (2)) where the logarithm of initial GDP per caput in the growth equation corresponding to the high PFI regime is included. The coefficient associated with log initial GDP per caput is equal to -0.001 with a corresponding t-statistic of -0.325. Thus, one of our identifying assumptions, namely the absence of convergence effects in the high PFI regime, is supported statistically by our empirical results.

In summary, the switching regression results suggest that nutritional growth traps exist, and that the quadratic specification uncovered in the simple pooling results stems from the co-existence of two regimes, one in which the PFI is high and in which the impact of the DES per caput on growth is large, a second in which the PFI is low and in which the impact of the DES per caput on growth is absent. The switching regression results also imply that a gap of 1.8

Figure 6

Estimation of a two-regime (high PFI, low PFI) switching regression
 Sample separation as determined by log GDP per capita and the PFI



Note: points to the southeast of the line are country-decades classified by the switching regression presented in Table 9 (system (1)) as belonging to the high PFI regime, points to the northwest are country-decades classified as belonging to the low PFI regime

TABLE 10

Nutritional growth traps?

Classification of countries by switching regression procedure

Countries belonging to a given regime during all decades for which data are available	
Countries stuck in high PFI regime through all decades for which data are available	Alghanistan, Angola, Burundi, Benin, Burkina Faso, Bangladesh, Bolivia, Botswana, Central African Republic, Cameroon, Congo, Dominican Republic, Ecuador, Ethiopia, Gabon, Ghana, The Gambia, Guatemala, Honduras, Haiti, India, Jamaica, Kenya, Liberia, Sri Lanka, Lesotho, Madagascar, Mali, Mozambique, Mauritania, Mauritius, Malawi, Niger, Nigeria, Nicaragua, Nepal, Pakistan, Peru, Philippines, Rwanda, Sudan, Senegal, Sierra Leone, El Salvador, Somalia, Swaziland, Chad, Togo, Thailand, Tanzania, Uganda, Republic of Yemen, Zaire, Zambia, Zimbabwe
Countries in low PFI regime through all decades for which data are available	Argentina, Australia, Austria, Belgium, Brazil, Barbados, Canada, Switzerland, Cyprus, Germany, Denmark, Spain, Finland, France, United Kingdom, Greece, Hong Kong, Ireland, Iceland, Israel, Italy, Jordan, Japan, Republic of Korea, Luxembourg, Mexico, Malta, Malaysia, Netherlands, Norway, New Zealand, Portugal, Paraguay, Singapore, Sweden, Trinidad and Tobago, Turkey, Uruguay, United States
Countries changing regime between decades	
Emerged from high PFI regime in the 70s	Algeria, Egypt, Morocco, Papua New Guinea, Syrian Arab Republic, Tunisia
Emerged from high PFI regime in the 80s	Myanmar, Colombia, Costa Rica, Indonesia, Swaziland
Emerged from high PFI regime in 70s, but returned to high PFI regime in 80s	Côte d'Ivoire, Guyana, Venezuela
Fell into high PFI regime in 80s	Chile, Panama

percentage points in the annual growth rate of GDP per caput can be accounted for by a country belonging to the high PFI regime.

4.3 Escaping the malnutrition trap: some tentative findings

Although it is wise to be cautious regarding econometric results based on a latent variables approach, it is interesting to examine how various observations (country-decades) are classified by our switching regression procedure. Apart from the set of countries that were members of the OECD in the 1960s, which are, unsurprisingly, classified into the low PFI regime, a certain number of countries stand out in the low PFI subsample. Details are provided in Table 10. For example Brazil, Jordan, the Republic of Korea, Mexico, Malaysia, Paraguay, Trinidad and Tobago and Uruguay are all classified into the low PFI regime starting with the 1960s. Botswana, Thailand and the Philippines, on the other hand, are classified in the high PFI regime into the 80s despite impressive growth rates of GDP, suggesting that inequality and the ensuing high rates of malnutrition have constrained what might have otherwise been even higher rates of growth.

The most interesting cases are provided by those countries that moved from the high PFI regime to the low PFI regime, indicating that those gains to growth attainable by improving the nutritional status of the population were exhausted. A group of five Middle East and North Africa (MENA) countries (Algeria, Egypt, Morocco, Syrian Arab Republic and Tunisia), plus Papua New Guinea emerged from the high PFI regime in the 70s, an indication that the constraints imposed on growth by inadequate nutrition (but not necessarily other constraints) were probably eliminated by the massive social programmes implemented in those Arab countries following the first oil price shock. This first group of countries is joined in the low PFI regime in the 80s by Myanmar, Colombia, Costa Rica, Indonesia and Swaziland. Côte d'Ivoire, Guyana, Venezuela are classified as having emerged from the high PFI regime during the 1970s only to return to it during the 1980s. Finally, Panama and Chile, after being classified as belonging to the low PFI regime for the 1960s and 1970s, are classified as having fallen into the high PFI regime during the 1980s.

It is worth stressing that being classified as belonging to the high PFI regime does not condemn a country to low rates of growth. What it does mean is that nutritional factors are important for such countries and that there is room for improving the growth rate of GDP per caput by increasing the DES per caput. In countries operating within the low PFI regime, on the other hand, nutritional concerns are of much more limited concern, and there remains no room to improve growth performance by increasing the DES per caput.

5. ENDOGENEITY AND STRUCTURAL ESTIMATION

The use of simultaneous equation models in the empirical study of growth has so far been extremely limited. On the one hand, this is because appropriate admissible instruments are notoriously difficult to come by, as noted in the context of the GMM results presented above. On the other, there has been considerable reticence on the part of the profession to "go out on a limb" and specify an estimable structural form that stems from a well-specified theoretical model. In this section, two structural econometric models are considered in which a growth regression is paired with a "transmission mechanism" equation.

5.1 Life expectancy

Although the Grossman model (1972) constitutes the foundation of the dynamic approach to the demand for health, as well as a theoretically sound basis for a model of life expectancy, relatively few growth theorists seem to be aware of its existence. In what follows, a continuous-time version of the "pure investment" Grossman model is sketched. This demonstrates how life expectancy may be endogenized within the context of a model of intertemporal optimization and, most importantly, provides solid theoretical foundations for the specification of a life expectancy equation which includes nutritional concerns among the explanatory factors.

In the "pure investment" Grossman (1972) model, the representative consumer allocates her revenue between a consumption good denoted here by c , and investment in a stock of health capital, denoted by h .¹¹ Investment in health capital obtains through expenditures, denoted here by p , which include medical expenditures *per se* as well other forms of expenditures which improve health. The consumer's budget constraint is thus given by:

$$(37) \quad wI(.) = c + p,$$

where w represents the wage rate (assumed here to be constant) and $I(.)$ is the individual's labour supply. The stock of health capital affects the individual's labour supply. The greater the stock of health capital, the smaller will be the amount of work time lost to ill health. This can be expressed by writing:

$$(38) \quad I = I(h), I_h(.) \geq 0, I_{hh}(.) \leq 0.$$

Grossman also assumes that there exists an upper bound on the labour supply of the individual, which can be expressed as:

$$(39) \quad \lim_{h \rightarrow \infty} I(h) = \bar{I}.$$

A crucial assumption of the model is that there exists a lower bound on the stock of health capital of the individual compatible with survival. Let $\underline{h}$ represent this lower bound, which will be defined as follows:

$$(40) \quad \exists \underline{h} \text{ such that } I(\underline{h}) = 0.$$

Human physiology also plays a role in the evolution of the stock of health capital. Thus, the law of motion of health capital will include a rate of depreciation. It is likely that, *ceteris*

¹¹ In his original formulation Grossman consider the time allocation problem faced by the consumer as well, and this within a discrete-time framework; what follows is a simplified, continuous-time treatment of the model.

paribus, this rate of depreciation will be quite small when an individual is young. However, it will tend to increase with age. This corresponds to the following expression:

$$(41) \quad \dot{h}_t = p_t - \delta(t)h_t.$$

The optimization problem faced by the representative agent is therefore given by:

$$(42) \quad \max_{\{c_t, m_t, h_t\}} \int_0^T U(c_t) e^{-\rho t} dt \quad \text{s.t.}$$

$$(43) \quad wl(h_t) = c_t + p_t,$$

$$(44) \quad \dot{h}_t = p_t - \delta(t)h_t,$$

where T represents the time of death of the individual, which will be endogenously determined within the model. Substituting from the budget constraint allows us to write the corresponding Hamiltonian as:

$$(45) \quad H_t = U(c_t) e^{-\rho t} + \mu_t (wl(h_t) - c_t - \delta(t)h_t),$$

where μ_t represents the costate variable. By Pontryagin's Maximum Principle, the necessary conditions for an optimum are given by:

$$(46) \quad \frac{\partial H_t}{\partial c_t} = U'(c_t) e^{-\rho t} - \mu_t = 0$$

$$(47) \quad \frac{\partial H_t}{\partial h_t} = \mu_t (wl_h(h_t) - \delta(t)) = -\dot{\mu}_t$$

plus the usual transversality condition. The first condition implies that the costate variable can be expressed as:

$$(48) \quad \mu_t = U'(c_t) e^{-\rho t}.$$

Differentiating with respect to time and rearranging yields:

$$(49) \quad \frac{\dot{\mu}_t}{\mu_t} = \dot{c}_t \frac{U''(c_t)}{U'(c_t)} - \rho.$$

The laws of motion of the system are therefore given by:

$$(50) \quad \dot{c}_t = \left(-\frac{U''(c_t)}{U'(c_t)} \right)^{-1} \left[(wl_h(h_t) - (\delta(t) + \rho)) + (wl(h_t) - c_t - \delta(t)h_t) \right],$$

and

$$(51) \quad \dot{h}_t = wl(h_t) - c_t - \delta(t)h_t.$$

The steady-state conditions then imply that:

$$(52) \quad 0 = \left(-\frac{U''(c_t^*)}{U'(c_t^*)} \right)^{-1} (wl_h(h_t^*) - (\delta(t) + \rho)),$$

and

$$(53) \quad 0 = w l(h_t^*) - c_t^* - \delta(t) h_t^*,$$

where, in contrast to what one usually obtains in a growth model, the steady-state stock of health capital is a function of time (expressed by writing h_t^* instead of h^*) because of the dependence of the depreciation rate of health capital on t . From the first condition, it follows that:

$$(54) \quad h_t^* = l_h^{-1} \left(\frac{\delta(t) + \rho}{w} \right).$$

Since $l_h(h_t)$ is a decreasing function, it follows that its inverse, $l_h^{-1}(\cdot)$, is so as well. If one considers an *ad hoc* specification in which the depreciation rate of health capital is a function not only of time but of some measure of the extent of malnutrition, such as the DES per caput, that is $\delta = \delta(t, DES)$, with $\partial \delta(t, DES) / \partial DES < 0$, it follows that the steady-state level of health capital, and thus life expectancy, will be an increasing function of the DES per caput. This provides a simple theoretical justification for the inclusion of nutritional variables in a life expectancy equation.

An additional justification for including the DES per caput in a life expectancy equation is provided by several well-known micro-econometric studies that have examined the question, although it should be noted that the focal point of this work has been concentrated on infant mortality. Martorell and Ho (1984), in their survey of the literature, note that "the studies reviewed here all show that severely malnourished children... have greatly increased mortality risks relative to normal children. Children with mild and moderate malnutrition... also showed increased mortality risks."¹² (p. 61) Since the variable used in the cross-country growth regressions is life expectancy at age zero, the increased mortality risk of malnourished children should be captured by this variable. The interested reader is referred to the excellent survey by Behrman and Deolalikar (1988) for more details on the relevant literature.

The Grossman model, as well as the micro-econometric evidence, suggest that nutritional concerns should be an important determinant of life expectancy at the aggregate, cross-country level. This intuition is confirmed empirically by an extremely simple regression presented in column (1) of Table 11, in which life expectancy at age zero is regressed on the two decade dummies, the two continent dummies, the initial level of GDP per caput, the DES per caput, the number of physicians per 10,000 inhabitants, and the growth rate of GDP per caput. The coefficient associated with the DES per caput is highly significant at the usual levels of confidence.¹³ Moreover, there is a potentially interesting "feedback" effect of the growth rate of GDP per caput on life expectancy. Essentially, in countries that grow faster, individuals

¹² See Pelletier *et al* (1994) for a recent contribution. It should be noted that Horton *et al*'s (1985) cross-country empirical results on the determinants of infant mortality are not particularly convincing when it comes to the impact of the price of "cheap calories". As with many of these cross-country studies done in the 1980s, the problem may simply lie with the poor quality of the data that were available at the time.

¹³ Note that when Preston (1980), in a well-known paper, included the excess of the DES above 1500 kcal/day in a life expectancy equation, he found the associated coefficient to be insignificant at the usual levels of confidence. This result remains unchanged when Preston moved to country-specific fixed effects.

TABLE 11
PFI, DES per caput, and economic growth
Transmission mechanisms : life expectancy
Estimation of a two-equation structural model
 (t-statistics below coefficients)

Dependent variable	(1)	(2)		(3)	
	Life expectancy at age zero	Growth rate of GDP per caput	Life expectancy at age zero	Growth rate of GDP per caput	Life expectancy at age zero
Method of estimation	OLS	GMM		GMM	
Intercept	9.538 2.171	-0.112 -3.303	9.788 2.183	-0.111 -3.318	9.813 2.194
1960s dummy	-3.113 -3.559	0.024 5.430	-4.653 -3.742	0.024 8.997	-4.664 -3.758
1970s dummy	-1.479 -1.717	0.017 4.406	-2.710 -2.499	0.018 4.860	-2.719 -2.513
Africa dummy	-5.976 -6.478	-0.002 -0.196	-5.079 -4.220		-5.154 -4.526
Latin America dummy	1.372 1.514	-0.014 -4.159	2.261 2.048	-0.014 -4.113	2.236 2.043
Log of initial GDP	5.231 7.859	-0.011 -1.567	5.344 7.353	-0.012 -2.443	5.370 7.526
Life expectancy at age zero		0.002 1.523		0.002 3.170	
DES per caput (kcal/day)	4.50E-03 3.786	8.45E-05 2.987	0.004 3.467	8.19E-05 3.271	0.004 3.532
DES per caput, squared		-1.53E-08 -3.392		-1.50E-08 -3.553	
Physicians per 10,000 inhab.	0.154 2.289		0.153 2.185		0.146 2.525
Growth rate of GDP per caput	54.62 3.722		129.03 2.733		128.64 2.729
Mean of dependent variable	58.40	0.022	58.40	0.022	58.40
Test of overidentifying restrictions: (degrees of freedom) p-value		n.a.		0.846	
Number of observations	215	215		215	

Note: in column (1), adjusted $R^2 = 0.852$, $\sigma^2 = 4.373$; method of estimation for systems (2) and (3), Generalized Method of Moments using exclusion restrictions in order to identify. Data source: Physicians per 10 000 inhabitants : World Bank Social Indicators.

live longer : an increase of the growth rate of GDP per caput of one percentage point (0.01) increases life expectancy at age zero by approximately six months. Both of these effects obtain, it should be noted, even though GDP per caput is included in the specification. This regression also performs remarkably well in explaining differences in life expectancy across countries : the associated adjusted R^2 is equal to 0.852.

In the next two columns in Table 11, results are presented corresponding to GMM estimation of the two-equation system constituted by a growth regression that mirrors that presented in column (7) of Table 7 (pooling results including life expectancy, the difference here being that life expectancy is assumed to be endogenous) as well as a life expectancy equation similar to the one presented in column (1) of Table 11. In the growth equation, it is striking that all coefficients are similar in size to those presented in column (7) of Table 7 (despite the loss of 76 observations because of the inclusion of our exogenous instrument, physicians per 10 000

inhabitants), with the possible exception of the coefficient associated with the SSA dummy which is now statistically indistinguishable from zero. In particular the coefficients associated with the DES per caput and the DES per caput squared are both statistically indistinguishable from those presented in the simple pooling results. In the life expectancy equation, on the other hand, the feedback effect of the growth rate of GDP per caput on life expectancy is now substantially larger: unsurprisingly, the OLS results presented in column (1) of Table 11, in which the growth rate of GDP per caput was assumed to be exogenous, tended to underestimate this effect. On the other hand, the impact of the DES per caput on life expectancy is remains statistically significant and of the same order of magnitude.

The identifying restriction that allows one to estimate this system by GMM is, of course, the inclusion of physicians per 10,000 inhabitants in the life expectancy equation, and its exclusion from the growth regression. Note that, when introduced into a growth regression, the coefficient associated with this variable is statistically indistinguishable from zero, lending some support to its use as an exogenous instrument. With the system presented in column (2), it is, of course, impossible to formally test the validity of this instrument given that the system is just identified.

In column (3) of the same Table, results are presented corresponding to the most parsimonious specification possible in the sense that all insignificant variables whose exclusion does not change the coefficients of interest in a statistically significant manner are dropped. In this case, the system is overidentified with 4 degrees of freedom and the standard Sargan test can be used in order to assess the validity of our set of overidentifying restrictions. The p-value associated with this test is equal to 0.846, implying that the appropriateness of the instruments cannot be rejected. This lends substantial statistical support to our results.

The results presented in column (3) of Table 11 allow one to carry out a first diagnostic regarding the relative magnitude of the indirect *versus* direct effects of the DES per caput on the growth rate of GDP per caput. Write the growth regression as:

$$(55) \quad Y_u = Z_u \beta + X_u \gamma + X_u^2 \theta + L_u \delta + v_u,$$

where Y_u is the growth rate of GDP per caput, Z_u is the vector of controls, X_u is the DES per caput, and L_u is life expectancy at age zero. Similarly, write the life expectancy equation as:

$$(56) \quad L_u = A_u \phi + X_u \pi + Y_u \mu + v_u,$$

where A_u is the vector of control variables in the life expectancy equation. Then the direct impact of the DES per caput on growth is given by:

$$(57) \quad \gamma + 2\theta X_u,$$

whereas its indirect impact, operating through life expectancy, is equal to:

$$(58) \quad \pi \delta.$$

If the feedback effects are included, the effects are given, respectively, by:

$$(59) \quad \frac{\gamma}{1 - \mu\delta} + \frac{2\theta}{1 - \mu\delta} X_u \quad \text{and} \quad \frac{\pi\delta}{1 - \mu\delta}.$$

Using equations (57) and (58), it can be seen that raising the DES per caput in all countries to 2770 kcal/day (the average level, suggested in the *Sixth World Food Survey*, at which the PFI would fall to zero) in those countries where the DES per caput is below this level would increase their annual growth rate of GDP per caput by 0.43 percentage points directly and by an

TABLE 12
PFI, DES per caput, and economic growth
Transmission mechanisms : life expectancy and schooling
Estimation of a three-equation structural model
Method of estimation : Generalized Method of Moments (GMM)
 (t-statistics below coefficients)

Dependent variable	(1)			(2)			(3)		
	Growth rate of GDP per caput	Life expectancy at age zero	Log of years schooling	Growth rate of GDP per caput	Life expectancy at age zero	Log of years schooling	Growth rate of GDP per caput	Life expectancy at age zero	Log of years schooling
Exogeneity assumption	Log schooling assumed endogenous : benchmark specification			Log schooling assumed exogenous			Log schooling assumed endogenous : parsimonious specification		
Intercept	-0.179	4.142	1.940	0.001	-4.293	5.873	-0.246		
	-3.128	0.984	1.099	0.051	-1.003	2.631	-9.743		
1960s dummy	0.025	-3.498	-0.002	0.024	-6.074	-0.561	0.024	-2.360	
	5.350	-3.222	-0.017	5.291	-5.325	-3.640	6.564	-3.830	
1970s dummy	0.013	-1.738	-0.077	0.018	-4.488	-0.553	0.012		
	2.927	-1.755	-0.759	4.189	-3.795	-3.655	3.802		
Africa dummy	0.000	-3.867	-0.148	0.004	-1.587	0.135		-4.040	-0.127
	-0.011	-3.208	-1.511	0.556	-1.043	0.863		-5.372	-2.430
Latin America dummy	-0.013	1.759	0.037	-0.016	4.134	0.412	-0.009		
	-3.201	1.742	0.382	-3.844	3.448	3.476	-3.875		
Log of initial GDP	-0.007	6.316	-0.643	-0.026	7.627	-1.814		7.113	-0.134
	-0.624	9.815	-1.395	-8.802	10.487	-2.888		28.657	-4.984
Log of initial GDP, squared			0.072			0.142			0.041
			2.388			3.829			12.716
Life expectancy at age zero	0.003			0.003			0.004		
	2.317			3.662			8.016		
Log schooling	-0.038			0.004			-0.066		
	-2.180			0.731			-7.235		
DES per caput (kcal/day)	7.8E-05	2.9E-03	5.8E-05	1.7E-05	0.002	-3.4E-04	8.1E-05	2.2E-03	
	2.008	2.995	0.611	1.263	1.260	-1.695	3.243	2.863	
DES per caput, squared	-1.4E-08			-4.1E-09			-1.9E-08		
	-2.331			-2.516			-3.777		
Physicians per 10,000 inhab.		0.115			0.030			0.082	
		2.156			1.068			2.989	
Growth rate of GDP per caput		115.98	-0.840		254.57	26.026		87.059	
		3.275	-0.191		8.455	4.686		4.007	
Mean of dependent variable	0.023	60.583	1.337	0.023	60.583	1.337	0.023	60.583	1.337
Test of over-identifying restriction: (degrees of freedom) p-value	(df = 2) 0.361			(df = 5) 0.000			(df = 13) 0.637		
Number of observations	178			178			178		

Note : test of overidentifying restrictions in the specification corresponding to the parsimonious system (3), but where log schooling is assumed to be exogenous has a p-value of 0.000.

additional 0.33 percentage points through the impact mediated by life expectancy. When the feedback effect of growth on life expectancy is included in the calculations (equation (59)), the corresponding figures are 0.55% and 0.42%. The total impact on the annual growth rate of per caput GDP is thus comprised between 0.77 and 0.97 percentage points, divided approximately equally between direct and indirect effects.

5.2 Schooling

Table 12 presents empirical results corresponding to a three-equation system constituted by (i) a life expectancy equation, (ii) a schooling equation, and (iii) a growth equation. Both life expectancy and schooling are assumed to be endogenous in the results presented in columns (1) and (3), whereas those results presented in column (2) correspond to a specification in which schooling is assumed to be exogenous.

The results, particularly with respect to the usual assumption of exogeneity of schooling in growth regressions, are particularly interesting. When schooling is assumed to be exogenous (column (2) in Table 12), three results obtain. First, the coefficient associated with schooling is statistically indistinguishable from zero in the growth equation. Second, convergence effects are of the usual negative sign and highly significant. Third, the coefficient associated with life expectancy in the growth equation is positive and of the same order of magnitude as for those results presented in Table 11.

These results, while interesting, are not robust empirically. This is because the overidentifying restrictions (with 5 degrees of freedom) are soundly rejected with a corresponding *p*-value that is smaller than 0.001. In contrast, when the same system is estimated assuming that schooling is endogenous in the growth regression, the test of the overidentifying restrictions is not rejected (*p*-value = 0.381). Moreover, convergence effects vanish in the growth regression and the coefficient associated with schooling in the same equation is now negative and statistically significant. Column (3) of the same Table presents results corresponding to the most parsimonious specification of the three equation system, in which schooling is assumed to be endogenous. Those results presented in column (1) are, unsurprisingly, reinforced by the increase in degrees of freedom and, as with the full system in which schooling is endogenous, the specification is not rejected by a test of the overidentifying restrictions (*p*-value = 0.637). In terms of the DES per caput variables in the growth regression, the quadratic specification is estimated quite precisely, as is the impact of the DES per caput in the life expectancy equation.

A possible source of concern in the results presented in Table 12 is that the schooling equation is mis-specified. Given the manner in which the GMM procedure exploits the correlation among equations, it is therefore quite possible that specification errors in the schooling equation are transmitted *via* the variance-covariance matrix to the coefficients estimated in the life expectancy and growth equations.

In order to assess whether this was indeed the case, Table 13 presents results using the two-equation specification of Table 11, but in which schooling is now included as an additional explanatory variable in the growth regression. Two sets of results are presented, corresponding to the schooling variable being either endogenous (columns (1) and (3)) or exogenous (columns (2) and (4)) in the growth equation.

Broadly speaking, the results corroborate those presented in Tables 11 and 12. First, with schooling assumed endogenous, the convergence effects in the growth regression vanish. Second, the quadratic specification in terms of the DES per caput in the growth regression remains statistically significant, particularly so in the parsimonious specification presented in column (3). Third, the coefficient associated with schooling is negative and statistically significant in

TABLE 13
PFI, DES per caput, and economic growth
Transmission mechanisms: life expectancy
Estimation of a two-equation structural model
Method of estimation: Generalized Method of Moments (GMM)
 (t-statistics below coefficients)

	(1)		(2)		(3)		(4)	
Dependent variable	Growth rate of GDP per caput	Life expectancy at age zero	Growth rate of GDP per caput	Life expectancy at age zero	Growth rate of GDP per caput	Life expectancy at age zero	Growth rate of GDP per caput	Life expectancy at age zero
Exogeneity assumption	Log schooling assumed endogenous; benchmark specification	Log schooling assumed endogenous; benchmark specification	Log schooling assumed exogenous; benchmark specification	Log schooling assumed exogenous; benchmark specification	Log schooling assumed endogenous; parsimonious specification	Log schooling assumed endogenous; parsimonious specification	Log schooling assumed exogenous; parsimonious specification	Log schooling assumed exogenous; parsimonious specification
Intercept	-0.175 -2.968	4.680 1.063	0.016 0.723	-7.103 -1.750	-0.177 -3.009	4.724 1.077	0.009 0.550	-9.399 -2.229
1960s dummy	0.025 5.267	-3.434 -3.153	0.025 4.908	-5.329 -4.770	0.025 6.479	-3.423 -3.160	0.023 5.705	-5.729 -4.811
1970s dummy	0.013 2.954	-1.718 -1.739	0.018 3.758	-4.025 -3.570	0.013 2.972	-1.709 -1.740	0.018 4.063	-4.488 -3.657
Africa dummy	0.001 0.076	-3.862 -3.191	0.010 1.180	-1.938 -1.344	-3.845 -3.234		-0.002 -0.002	
Latin America dummy	-0.013 -3.178	1.754 1.739	-0.014 3.025	3.192 2.766	-0.013 -3.166	1.749 1.734	-0.016 -3.732	4.043 3.559
Log of initial GDP	-0.007 -0.694	6.235 9.281	-0.034 -8.692	7.619 11.418	-0.006 -0.642	6.231 9.286	-0.029 -6.983	6.165 11.223
Life expectancy at age zero	0.003 2.245		0.005 4.246		0.003 3.811		0.004 5.029	
Log schooling	-0.038 -2.185		-0.004 -0.581		-0.040 -2.251		-0.002 -0.482	
DES per caput (kcal/day)	7.3E-05 1.635	2.9E-03 2.988	-1.1E-05 -0.809	2.5E-03 2.231	7.2E-05 1.957	2.9E-03 2.994	7.9E-06 0.615	1.9E-03 1.519
DES per caput, squared	-1.3E-06 -1.943		-1.7E-10 -0.105		-1.3E-06 -2.186		-2.6E-09 -1.561	
Physicians per 10 000 inhab.		0.131 1.985		-0.013 -0.526		0.133 2.013		0.001 0.060
Growth rate of GDP per caput		113.81 3.203		222.24 7.197		113.66 3.201		258.62 10.415
Mean of dependent variable	0.023	60.583	0.023	60.583	0.023	60.583	0.023	60.583
Test of overidentifying restriction: (degrees of freedom) p-value	(df=1) 0.184		(df=3) 0.000		(df=2) 0.412		(df=4) 0.000	
Number of observations	178		178		178		178	

the system corresponding to column (1) and remains so in the parsimonious specification presented in column (3). Fifth, the specifications in which schooling is assumed to be exogenous are strongly rejected by the test of the overidentifying restrictions, while the opposite is true when schooling is assumed endogenous (p-values equal to 0.184 and 0.412, respectively, in columns (1) and (3)).

These results confirm our previous findings of the existence of both a direct impact of the DES per caput on the growth rate of GDP per caput, as well as an indirect effect that operates through the impact of nutrition on life expectancy. They also raise serious doubts concerning

the concept of conditional convergence since, once schooling is assumed endogenous in the growth equation, the coefficient associated with initial GDP per caput becomes statistically indistinguishable from zero. Finally, they imply that convergence effects would appear to operate through differences in schooling, since the coefficient associated with this variable is negative and statistically significant at the usual levels of confidence.

In quantitative terms, the results presented in system (3) confirm the validity of the quadratic specification in terms of the DES per caput (although it should be noted that this specification is sensitive to the inclusion of country-specific fixed effects or first differencing). The critical value of the DES per caput at which the impact of nutrition on growth becomes negative in this case is equal to 2732 kcal /day, which is remarkably close to the level —2770 kcal / day— estimated by the *Sixth World Food Survey* as being sufficient to eliminate food inadequacy altogether.

6. THE EFFICIENCY COST OF HUNGER: A QUANTITATIVE ASSESSMENT

Given the plethora of results concerning the impact of nutrition on the growth rate of GDP per caput, corresponding to different estimation methods, it is time to present a quantitative assessment of the impact of a reduction in the PFI or an increase in the DES per caput. Results of these simulation exercises are summarized in Table 14 for the PFI and in Table 15 for the DES per caput.

In each Table, four sets of results are presented. The first column reports the impact on the mean rate of growth in the sample used in the corresponding estimation, while including those countries in which the PFI is zero or the DES per caput is above 2770 kcal / day. The second column focuses attention on a subsample comprising those countries in which the PFI is positive or in which the DES per caput is below 2770 / day. The third column narrows the focus even further, and considers the impact on the mean rate of growth of those countries belonging to SSA. Finally, the fourth column presents results for the same set of African countries as the third column, but takes the Svedberg critique into account by assuming that the PFI is overestimated in the FAO data by a factor of 20 percent or that the DES per caput is underestimated, also by a factor of 20 percent.

Several results are worthy of mention. First, note that the impact on growth has been classified in the Tables in ascending order on the basis of the first column. That is, the outcomes of simulations are reported starting with the estimation method that produces the lowest impact on growth, and progressively move up to the estimation method that produces the greatest impact on growth. In Table 14, country-specific fixed effects produce the lowest impact of the elimination of food inadequacy on growth, ranging from 0.34 percentage points in the case of the full sample to 0.64 percentage points in the case of SSA.

Second, in the case of the results based on increasing the DES per caput to 2770 kcal / day (Table 15), the estimation method that produces the lowest estimated impact on growth is given by the Sachs-Warner model. In both Tables, it is GMM with first differencing that produces the greatest impact on growth. For the PFI, the shortfall in the annual growth rate of GDP per caput caused by hunger is equal to 2.94 percentage points, rising to 4.63 percentage points in the case of SSA even when one assumes that the PFI, as currently measured by the FAO, is overestimated by 20 percent. For the DES per caput, the corresponding figures are 4.7 and 4.04 percentage points, respectively. These are extremely large numbers, and it is ironic

TABLE 14

The (efficiency) cost of hunger : a quantitative assessment

Impact on the growth rate of per caput GDP of eliminating food inadequacy

Sample	Full sample	PFI > 0	Africa, PFI > 0	Africa, PFI overestimated by 20%, PFI > 0
Country specific fixed effects: column (3) of Table 3	0.0034	0.0047	0.0064	0.0051
Country-specific fixed effects, life expectancy included: column (3) of Table 7	0.0046	0.0063	0.0057	0.0069
Country-specific fixed effects, schooling included: column (3) of Table 8	0.0055	0.0075	0.0103	0.0083
Benchmark pooling results: column (4) of Table 1	0.0064	0.0087	0.0120	0.0096
Between estimator: column (1) of Table 5	0.0093	0.0127	0.0174	0.0140
Sachs-Warner model, logistic specification: column (3) of Table 6	0.0145	0.0253	0.0310	0.0285
Augmented Solow model, logarithmic specification: column (2) of Table 2	0.0182	0.0253	0.0310	0.0285
GMM estimation with first-differencing: column (6) of Table 4	0.0294	0.0401	0.0578	0.0463

TABLE 15

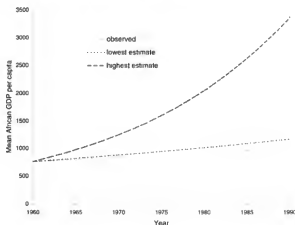
The (efficiency) cost of hunger : a quantitative assessment
Impact on the growth rate of per caput GDP of raising DES per caput
to 2770 kcal/day in countries in which it is below that level

Sample	Full sample	DES per caput < 2770	Africa, DES per caput < 2770	Africa, DES per caput assumed underestimated by 20%, DES per caput < 2770
Single equation specifications				
Sachs-Warner model (column (2) of Table 8)	0.0023	0.0034	0.0039	0.0016
Pooling results, quadratic specification, life expectancy included (column (7) of Table 7)	0.0048	0.0069	0.0086	0.0027
Between estimator, linear specification (column (3) of Table 5)	0.0050	0.0071	0.0085	0.0038
Benchmark pooling results, linear specification (column (7) of Table 1)	0.0050	0.0072	0.0086	0.0038
Country-specific fixed effects, linear specification, schooling (column (6) of Table 8)	0.0070	0.0101	0.0120	0.0053
Country-specific fixed effects, linear specification (column (5) of Table 3)	0.0080	0.0115	0.0137	0.0060
Augmented Solow model, logarithmic specification (column (3) of Table 2)	0.0080	0.0123	0.0112	0.0045
Benchmark pooling results, quadratic specification (column (6) of Table 1)	0.0063	0.0119	0.0147	0.0051
Country-specific fixed effects, linear specification, life expectancy (col. (6) of Table 7)	0.0088	0.0126	0.0150	0.0066
Pooling results, quadratic specification, schooling included (column (7) of Table 8)	0.0091	0.0130	0.0162	0.0053
Switching regression specification, high PFI regime (column (1) of Table 9)	0.0093	0.0133	0.0159	0.0070
Between estimator, quadratic specification (column (4) of Table 5)	0.0103	0.0148	0.0183	0.0062
GMM estimation with first-differencing (column (6) of Table 4)	0.0476	0.0704	0.0675	0.0404
Simultaneous equation specifications				
Direct effect, no feedback (column (3) of Table 11)	0.0031	0.0043	0.0054	0.0010
Indirect effect through life expectancy, no feedback (column (3) of Table 11)	0.0024	0.0033	0.0039	0.0013
Direct effect, feedback included (column (3) of Table 11)	0.0040	0.0055	0.0070	0.0013
Indirect effect through life expectancy, feedback included (column (3) of Table 11)	0.0030	0.0042	0.0050	0.0017
Direct effect, schooling included, no feedback (column (3) of Table 13)	0.0023	0.0034	0.0041	0.0005
Indirect effect through life expectancy, schooling, no feedback (column (3) of Table 13)	0.0031	0.0045	0.0053	0.0015
Direct effect, schooling, feedback included (column (3) of Table 13)	0.0036	0.0053	0.0064	0.0008
Indirect effect through life expectancy, schooling, feedback incl. (col. (3) of Table 13)	0.0048	0.0070	0.0082	0.0024

that they correspond to an estimation procedure, as well as an assumption regarding the levels of the DES per caput and the PFI, that answer those (eminently valid) criticisms regarding the data enunciated by Svedberg (1999). Figure 7 provides an illustration of the evolution of the mean level of African GDP per caput as it appears in the data, as it would have appeared in the absence of malnutrition using the lowest estimate of the impact of food inadequacy on growth reported in Table 14 (fourth column), and as it would have appeared using the highest estimate reported in Table 15.

If the range of figures generated by the econometric work makes one uncomfortable and one wishes to stick to a single number, caution and those estimation techniques that are most

FIGURE 7
The (efficiency) cost of hunger : a quantitative assessment
 Evolution of mean GDP per caput in sub-Saharan Africa



commonly utilized in the econometric literature suggest formulating a quantitative assessment based upon (i) simple pooling results or (ii) simple country-specific fixed effects (the latter at least control for unobserved country-specific heterogeneity). It also turns out that these two estimation techniques produce results that correspond to the mid-point between the highest and lowest estimates reported. Estimates are presented in Table 16, where countries are classified differently with respect to Tables 14 and 15. Here, the division is between countries with above-median levels of the PFI versus countries with below-median levels of the PFI. The mean loss in the annual growth rate of GDP per caput caused by the DES per caput being below 2 770 kcal/day is reported. If the vision concerning the cost of hunger is based on the simple pooling results with the quadratic term in the DES per caput, then it is seen that the annual growth rate of GDP per caput was reduced by 1.6 percentage points by an inadequate level of DES per caput. This is illustrated graphically in Figure 8. From a mean difference of just less than \$US

TABLE 16
The (efficiency) cost of hunger : a quantitative assessment
 Loss in annual growth rate of GDP per caput caused by DES per caput being below 2 770 kcal/day

Estimation method	Loss in annual growth rate of GDP per caput caused by DES per caput being below 2,770 kcal / day	
	Countries with above-median PFI	Countries with below-median PFI
Pooling results with quadratic term in DES per caput	1.597	0.122
Country-specific fixed effects, linear in DES per caput	1.137	0.128

Note: average annual growth rate of GDP per caput of countries with below-median PFI is 1.134%; for countries with above-median PFI, it is 2.950%.

7. CONCLUDING REMARKS

The basic story told by the empirical results reported in this paper is that nutrition matters, and that inadequate nutrition, as measured by positive values of the PFI or shortfalls in the DES per caput, significantly reduces the growth rate of per caput GDP. In contrast to much of the recent literature, that has identified increasingly esoteric variables as pieces of the explanation for cross-sectional differences in growth performance, it is clear that differences in nutrition constitute one of the fundamental, and eminently reasonable, explanations for the observed heterogeneity in growth rates across countries.

It is worth noting, however, that an alternative interpretation of the results is possible. This alternative interpretation stems from the manner in which the PFI, in particular, is calculated. Analytically speaking, the point of departure for the calculation of the PFI is necessarily the consumer's optimization problem. Write the solution to this problem as:

$$(60) \quad c^*(p, y) = \arg \max_{[c]} U(c) \text{ s.t. } p \cdot c \leq y,$$

where c is the consumer's vector of consumption, p is the price vector, and y is the consumer's income.

Let $c_f^* = c_f^*(p, y)$ denote the consumer's optimal level of food consumption, which is simply one of the elements of c^* , and which will be measured in kcal/day. Let income in the population concerned be distributed according to the probability density function $f(y)$ over the interval $[0, \bar{y}]$. Then by the usual theorem concerning the distribution of the transformation of a random variable (Roussas, 1997, Theorem 2, p. 216), food consumption will be distributed according to the probability density function $g(c_f^*)$, where:

$$(61) \quad g(c_f^*) = \begin{cases} f(c_f^{*-1}(p, c_f^*)) \left| \frac{d}{dc_f^*} c_f^{*-1}(p, c_f^*) \right|, & c_f^* \in [c_f^*(p, 0), c_f^*(p, \bar{y})] \\ 0, & \text{otherwise,} \end{cases}$$

where $c_f^{*-1}(p, c_f^*)$ is the partial inverse of optimal food consumption with respect to y . It follows that, when one chooses a calorie cutoff point, denoted by $\underline{c}_f$, below which an individual is assumed to be inadequately fed, one is, in fact, choosing a threshold level of income, given by $\underline{y} = c_f^{*-1}(p, \underline{c}_f)$. This implies that computing a measure of the prevalence of food inadequacy is equivalent, analytically, to computing a poverty rate, since establishing a calorie cutoff point is equivalent to setting a poverty line.

The consequence is that the empirical results reported in this paper suggest that eliminating, or at least significantly reducing, poverty, will have an important quantitative impact on the growth rate of GDP per caput. From the empirical standpoint, it is clear that data corresponding to a greater number of country-decades is available when one works with the DES per caput or the PFI than when one works with the best data regarding income inequality available, recently pieced together by Deininger and Squire (1996). Indeed, replacing the DES per caput with the share of national income accounted for by the first quintile of the income distribution in the growth regressions presented in Table 1 of this paper reduces the number of observations from 314 to 151. In the case of the Gini coefficient, the corresponding number is 185. While the PFI or the DES per caput are not perfect measures of the incidence of poverty, they are perhaps adequate, and our empirical results show that the goals of "a world free of poverty" (The World Bank) or "a world free of hunger" (FAO) are complementary, and may not only improve human welfare in the static sense, but contribute to raising the rate of economic growth.

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This paper investigates the relationship between nutrition and economic growth at the aggregate level by examining the magnitude of the effects of undernourishment on economic growth and identifying the channels of transmission of such effects (direct effects on productivity and via impacts on health). In addition to this basic relationship, a number of other important relationships are investigated: (a) regional differences regarding the impact of under-nourishment on growth; (b) the impact that possible errors in measuring nutritional variables may have on the robustness of the estimated nutrition-growth relationship; and (c) the existence of "nutritional traps", i.e. the vicious circle of low nutrition-low economic growth-low nutrition. The basic conclusion of the paper – that undernourishment can be a serious handicap in the efforts of countries to achieve economic growth – suggests that actions taken to feed the hungry have a strong growth dimension in addition to their humanitarian character. This paper makes a significant contribution to the literature on the factors that account for the differences in growth performance across countries and regions.

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